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THE AMOUNT AND COMPOSITION OF THE DRAINAGE THROUGH UNMANURED AND UNCROPPED LAND, BARNFIELD, ROTHAMSTED.

BY N. H. J. MILLER, PH.D., F.I.C.

(*Lawes Agricultural Trust.*)

DURING the last sixty years numerous percolation and evaporation experiments have been made in this country and elsewhere. The method employed has been that originally used by Dalton, which has the advantage that the chemical and physical properties of the soil may, if desired, be thoroughly investigated. In addition to these experiments in which the evaporation from the soil, or from the soil with vegetation, is estimated by deducting the amount of drainage from the rainfall of the same period, numerous determinations of soil moisture have been made in the United States, from which evaporation may be directly determined. The difference between the estimated evaporation and the rainfall gives of course the amount of percolation.

Recently, King (9) has determined the evaporation from soils supplied from below with a constant water-supply, by means of large cylinders 4 feet in diameter and 2 feet deep. He has also determined the amounts of water evaporated by plants growing in similar cylinders 4 feet deep.

The Rothamsted gauges differ from those of Dalton in containing undisturbed soil. Soil which has been put into cylinders and subjected to the action of rain, will no doubt, as time goes on, acquire a more and more natural condition of consolidation, but we cannot know when this desirable condition is completed and can only take it for granted after a considerable time. The Barnfield gauges are free from this disadvantage, and as a means of measuring drainage, which is what they were mainly intended for, leave very little to be desired. As regards, however, the

relation of the constituents of the drainage to those of the soil, our knowledge must always be somewhat imperfect, since it is obviously impossible to obtain exact estimates of what the soil originally contained.

The results relating to the amounts of drainage and of nitrogen as nitrates in the drainage have been published each year from 1882 to 1901 in the Rothamsted "*Memoranda*" and recently in "*Field Plans*." Collected results relating to percolation only were published by Gilbert in 1891 (5), and more recently by R. H. Scott (7); whilst the more complete paper of Lawes, Gilbert, and Warington (3) deals with the whole subject, and contains the chemical results up to April, 1881.

On the present occasion it is proposed to bring together the whole of the results from the commencement. It will, however, be desirable first of all to give a short account of the gauges, as the earlier papers on the subject are not always accessible.

The three Rothamsted drain-gauges, having each an area of 1/1000th of an acre, were constructed in the summer of 1870 by undermining the soil at the desired depths (20, 40, and 60 inches respectively), and inserting perforated iron plates beneath the soil to support it as the undermining proceeded. When this was completed, trenches were made on the other three sides of the blocks of soil, and these were then isolated by means of 4½ inch brick walls. The external soil was then returned.

In 1874, leakage from the outside being suspected, the outsides of the walls of the gauges were exposed and covered with cement, and their thickness increased by another 4½ inches of bricks. In 1879, one of the walls of the 20-inch gauge received an extra coating of cement on its outer surface. Since then no structural alteration has been made in any of the gauges.

The drainage passing through the perforated iron plates which support the soil, falls into zinc funnels and flows from these into the measuring cylinders. During the first three years, however, the drainage was collected in carboys and weighed.

The Rothamsted soil[1] may be described as a rather heavy loam, with a reddish-yellow subsoil over chalk. Both the surface and the subsoil contain very large, and also very variable, amounts of flints.

As regards the cropping and manuring of the portion of the field on which the gauges were built it should be stated that before 1870 it

[1] H. B. Woodward, 'Report on the Soils and Subsoils of the Rothamsted Estate,' *Summary of Progress of the Geological Survey for* 1903.

had been under ordinary arable cultivation, artificial manures generally with guano, being employed. In 1870 the land was fallow.

In June, 1870, samples of soil were taken near the position now occupied by the gauges, both on the bare ground and on the barley land beyond. In the following table are given the results of nitrogen determinations made at the time in the samples from the bare ground, together with more recent determinations of calcium carbonate and chlorine. The amounts per acre are calculated from average weights of Rothamsted soils generally: for the first 9 inches, 2,400,000 lbs., for the second 9 inches 2,650,000, for the third and fourth 9 inches 2,700,000, and for the lower depths 2,800,000 lbs. per acre.

TABLE I.

Amounts of Nitrogen, Chlorine, and Calcium Carbonate in Soil Samples taken from the Bare Ground near the Gauges in 1870.

	In fine, dry soil			Per Acre		
	Nitrogen	Chlorine	Calcium carbonate	Nitrogen	Chlorine	Calcium carbonate
	per cent.	per cent.	per cent.	lbs.	lbs.	lbs.
First 9 inches	0·146	0·00242	3·06	3,501	58·1	73,440
Second ,, ...	0·078	0·00195	0·32	2,067	51·7	8,480
Third ,, ...	0·076	0·00190	0·12	2,052	51·3	3,240
Fourth ,, ...	0·076	0·00192	0·15	2,052	51·8	4,050
Fifth ,, ...	0·061	0·00199	0·11	1,708	55·7	3,080
Sixth ,, ...	0·057	0·00158	0·18	1,596	44·2	5,040

According to these estimates the initial amounts of the three constituents in the soil of the 20-, 40-, and 60-inch gauges will be in lbs. per acre as follows:

	Nitrogen	Chlorine	Calcium carbonate
Soil 20 inches deep.........	6,027	121	82,640
,, 40 ,, ...	10,434	238	90,579
,, 60 ,, ...	14,043	342	100,690

I. PERCOLATION AND EVAPORATION.

The average yearly amounts of water percolating through 20, 40, and 60 inches of soil are very similar and amount to about 14 inches, or approximately half the rainfall. The results obtained with the

20- and 60-inch gauges are indeed practically identical[1]; whilst the 40-inch gauge yields on the average nearly 1 inch more drainage than the others.

TABLE II.

Yearly Amounts of Drainage through 20, 40, *and* 60 *inches of Bare Soil.*

Sept. 1 to Aug. 31	Rain-fall	Drainage			Drainage °/₀ of Rainfall			Evaporation		
		20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge
	inches	inches	inches	inches				inches	inches	inches
1870–1	27·55	9·64	9·42	5·81	35·0	34·2	21·1	17·91	18·13	21·74
1–2	29·02	9·69	9·39	8·24	33·4	32·4	28·4	19·33	19·63	20·78
2–3	30·66	14·35	13·67	12·03	46·8	44·6	39·2	16·31	16·99	18·63
3–4	21·69	5·74	5·40	3·94	26·5	24·9	18·2	15·95	16·29	17·75
4–5	31·61	12·25	12·72	10·30	38·7	40·2	32·6	19·36	18·89	21·31
5–6	31·98	14·75	16·87	15·46	46·1	52·7	48·3	17·23	15·11	16·52
6–7	39·28	19·63	22·07	20·20	50·0	56·2	51·4	19·65	17·21	19·08
7–8	32·65	14·72	16·44	14·84	45·1	50·4	45·5	17·93	16·21	17·81
8–9	41·05	24·44	26·03	24·38	59·5	63·4	59·4	16·61	15·02	16·67
9–80	21·36	6·89	7·39	6·50	32·3	34·6	30·4	14·47	13·97	14·86
1880–1	36·77	22·38	22·84	21·26	60·9	62·1	57·8	14·39	13·93	15·51
1–2	32·31	15·81	16·08	14·32	48·9	49·8	44·3	16·50	16·23	17·99
2–3	34·71	20·82	21·72	19·72	60·0	62·6	56·8	13·89	12·99	14·99
3–4	25·77	11·86	12·00	11·21	46·0	46·6	43·5	13·91	13·77	14·56
4–5	26·78	14·82	15·14	13·98	55·3	56·5	52·2	11·96	11·64	12·80
5–6	31·02	17·37	18·41	16·57	56·0	59·3	53·4	13·65	12·61	14·45
6–7	23·61	10·64	12·58	11·72	45·1	53·3	49·6	12·97	11·03	11·89
7–8	30·50	13·96	15·58	14·67	45·7	51·1	48·1	16·54	14·92	15·83
8–9	30·09	14·64	15·82	14·33	48·7	52·6	47·6	15·45	14·27	15·76
9–90	27·43	13·16	13·60	12·74	48·0	49·6	46·4	14·27	13·83	14·69
1890–1	23·41	9·95	9·70	9·73	42·5	41·4	41·6	13·46	13·71	13·68
1–2	29·68	16·50	17·43	16·47	55·6	58·7	55·5	13·18	12·25	13·21
2–3	24·08	11·58	12·35	12·10	48·1	51·3	50·3	12·50	11·73	11·98
3–4	29·55	13·36	14·11	14·07	45·2	47·7	47·6	16·19	15·44	15·48
4–5	28·94	15·50	16·95	16·31	53·5	58·6	56·4	13·44	11·99	12·63
5–6	24·37	9·84	10·75	10·35	40·4	44·1	42·5	14·53	13·62	14·02
6–7	37·24	21·88	23·86	22·80	58·8	64·1	61·2	15·36	13·38	14·4[illegible]
7–8	19·51	5·95	6·66	6·47	30·5	34·1	33·2	13·56	12·85	13·0[illegible]
8–9	24·70	11·99	12·48	12·48	48·6	50·5	50·5	12·71	12·22	12·2[illegible]
9–1900	31·02	16·33	16·93	17·02	52·6	54·6	54·9	14·69	14·09	14·0[illegible]
1900–1	24·30	10·91	12·35	11·92	44·9	50·8	49·1	13·39	11·95	12·3[illegible]
1–2	23·26	8·75	9·32	9·44	37·6	40·1	40·6	14·51	13·94	13·8[illegible]
2–3	31·25	16·33	17·09	17·59	52·3	54·7	56·3	14·92	14·16	13·6[illegible]
3–4	31·50	17·68	17·92	18·29	56·1	56·9	58·1	13·82	13·58	13·21
4–5	25·30	10·10	10·45	10·36	39·9	41·3	40·9	15·20	14·85	14·94

[1] It may be mentioned that the summer of 1870, at the end of which the gauges were made, was very dry and that the soil must have lost considerable amounts of water by evaporation from the exposed sides, the deeper the gauge the greater, of course, the loss. Evidence of this is furnished by the first year's percolation results, the 20-inch gauge giving 9·64 and the 60-inch gauge only 5·81 inches. When this first year is excluded, the averages (34 years) for the two gauges differ by only 0·08 inch.

The yearly amounts of drainage show in each case (Table II) great variations, depending partly on the total rainfall and partly on the distribution of the rain during the year. Averages of several years arranged according to the magnitude of the rainfall show a regular increase in the amount of drainage (see Table III), but in individual years there may be low drainage with relatively high rainfall, and *vice versâ*. In the year 1881–2, for instance, a year of high rainfall, following a year of still greater rainfall, the percentage of drainage through 60 inches of soil was slightly below the average, although as a rule a high rainfall is coincident with a relatively higher amount of drainage. In 1889–90, a year of average rainfall, also following one of high rainfall, the amount of drainage was low in all three gauges. The generally small differences between the yearly drainage through 20 and 60 inches of soil seem to have no connexion with the amount of the rainfall, and are difficult to account for. During the first twenty-two years of the experiments the 20-inch gauge generally gave more drainage than the 60-inch gauge; during the last thirteen years the reverse has occurred without exception.

TABLE III.

Average Amounts of Drainage and Evaporation in years of Low, Average, and High Rainfall (60-*inch Gauge*), 1870–1 *to* 1904–5.

	Rainfall	Drainage		Evaporation
	inches	inches	per cent.	inches
Rainfall below 26 inches......	23·45	9·69	41·3	13·76
,, 26—30 inches.........	28·42	12·52	44·1	15·90
,, above 30 inches......	33·35	17·11	51·3	16·24

The differences between the amounts of rain and drainage—due partly to evaporation and partly to retention by the soil, when we are dealing with individual years or months, and to evaporation alone in the case of averages of several years—show less variation from year to year than either rainfall or drainage. The evaporation from the 20-inch gauge has varied from 11·96 to 19·33 (average 15·13 inches), and from the 60-inch gauge from 11·89 to 21·74 (average 15·32 inches). Most of the high results were obtained in the first few years, during a period of unusually heavy rainfall.

Results of percolation experiments made by Dickinson and Evans (2) at Hemel Hempstead, with Dalton gauges containing soil covered with

grass, showed a yearly evaporation of 19·97 inches with a rainfall of 25·55 inches. Similar results were obtained by Greaves (1) at Lea Bridge, turfed soil evaporating 18·14 inches (average of 14 years). Greaves also determined the evaporation from a surface of water, which he found amounted to 20·66 inches per annum. The more recent water-evaporation experiments in St Pancras, London, published by Mill (8) gave, however, much lower results, the average yearly amount (19 harvest years) being only 15·55 inches.

TABLE IV.

Monthly Amounts of Drainage through 20, 40, *and* 60 *inches of Soil. Average* 35 *years.*

1870–1 to 1904–5	Rainfall	Drainage			Drainage per cent. of rain			Evaporation		
		20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge
	inches	inches	inches	inches				inches	inches	inches
September	2·51	0·86	0·81	0·74	34·3	32·3	29·5	1·65	1·70	1·77
October......	3·23	1·83	1·80	1·64	56·7	55·7	50·8	1·40	1·43	1·59
November...	2·82	2·10	2·15	2·01	74·5	76·2	71·3	0·72	0·67	0·81
December...	2·52	2·02	2·14	2·01	80·2	84·9	79·8	0·50	0·38	0·51
January ...	2·29	1·79	2·02	1·92	78·2	88·2	83·8	0·50	0·27	0·37
February ...	1·94	1·39	1·53	1·44	71·7	78·9	74·2	0·55	0·41	0·50
March	1·88	0·92	1·06	1·00	48·9	56·4	53·2	0·96	0·82	0·88
April	1·90	0·50	0·57	0·53	26·3	30·0	27·9	1·40	1·33	1·37
May	2·08	0·47	0·54	0·49	22·6	26·0	23·6	1·61	1·54	1·59
June	2·41	0·65	0·67	0·64	27·0	27·8	26·6	1·76	1·74	1·77
July	2·70	0·68	0·69	0·65	25·2	25·6	24·1	2·02	2·01	2·05
August	2·69	0·63	0·63	0·58	23·4	23·4	21·6	2·06	2·06	2·11
Sept.—Dec.	11·08	6·81	6·90	6·40	61·5	62·3	57·8	4·27	4·18	4·68
Jan.—April	8·01	4·60	5·18	4·89	57·4	64·7	61·1	3·41	2·83	3·12
May—Aug.	9·88	2·43	2·53	2·36	24·6	25·6	23·9	7·45	7·35	7·52
Oct.—Mar.	14·68	10·05	10·70	10·02	68·5	72·9	68·3	4·63	3·98	4·66
April—Sept.	14·29	3·79	3·91	3·63	26·5	27·4	25·4	10·50	10·38	10·66
Year......	28·97	13·84	14·61	13·65	47·8	50·4	47·1	15·13	14·36	15·32

With regard to monthly percolation the average results set out in Table IV show that the maximum drainage occurs in November, that it gradually decreases until May, after which there is a regular rise to September, followed by a considerable rise in October. The monthly differences between the drainage of the 20-inch gauge and that of the 60-inch gauge are very regular and are best shown as percentages of

the rain (Fig. 1). From January to May the 60-inch gauge yields a decreasing excess of drainage over the 20-inch gauge, whilst from June to December (particularly from September to November) the excess of drainage is from the 20 inch gauge. The differences are very difficult to account for and may be due to variations in temperature and consequently in viscosity (to which, presumably, the 20-inch gauge would be the more liable to be influenced), to barometric pressure, or may be connected with the access, escape, and retention of air which will vary according to the depth of the soil.

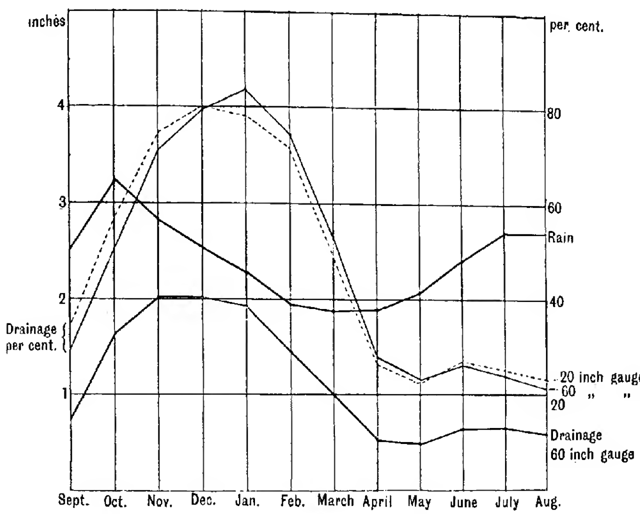

FIG. 1. Rainfall and drainage through 60 inches of soil. Drainage through 20 and 60 inches of soil per cent. of rain. Average 35 years.

In Wollny's (10) experiments with soil from 5 cm. to 30 cm. deep, it was found that the amount of drainage diminished with the depth of the soil up to a certain point (15 cm. of soil) and then increased. The results are, however, not comparable with those just described, as the deepest soil (30 cm.) was not much more than half the depth of the 20-inch gauge. The percentage of water in Wollny's soils increased considerably with the depth of the soil up to 20 cm., and then remained fairly constant.

The average number of days on which drainage has been recorded is 123 in the case of the 60-inch gauge. The monthly averages are as follows:

October	13·0 days	April	8·9 days
November	14·5 ,,	May	7·0 ,,
December	14·9 ,,	June	6·5 ,,
January	14·1 ,,	July	6·8 ,,
February	12·9 ,,	August	5·9 ,,
March	11·3 ,,	September	7·4 ,,

The number of rainy days (see this vol., p. 299) falls from 18 in October to 13 in March, and varies between 12 and 14 in the summer months.

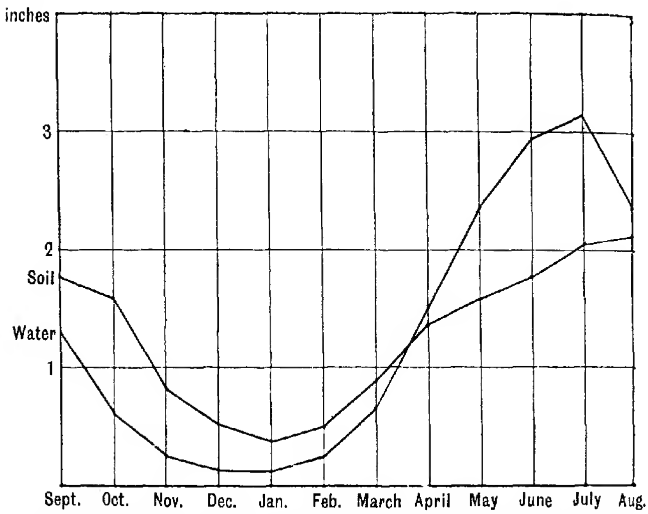

FIG. 2. Estimated evaporation from the soil of the 60-inch gauge; and evaporation from water (Mill).

A comparison of the monthly differences between rain and drainage with the amounts actually evaporated from a surface of water (Mill, *loc. cit.*), would seem to indicate that from March to September these differences are mainly due to evaporation, and that from October to February a good deal is due to retention by the soil. When, however, we select from the monthly results those which have followed a month at least of high rainfall, it is seen that in most cases the estimated

amounts of evaporation do not differ greatly from the average. With the exception of October it is probable that the average monthly results indicate almost exclusively evaporation. In October more of the difference between rainfall and drainage would seem to be due to absorption (Fig. 2).

An excess of drainage over the monthly rain has occurred on fifteen occasions, but always from November to March, and chiefly in January and February. On each occasion the excess has been observed in the case of the 40-inch gauge, whilst the 60- and 20-inch gauges have only yielded an excess on nine and seven occasions respectively. It is due either to the soil becoming frozen, or to an excess of water at the end of the month not having had time to percolate. Excesses of daily drainage over the amount of rain occur at all times of the year, and may be due to the rate of percolation being for a time slower than the supply of rain, or in some cases perhaps to a rise in temperature resulting in the diminished viscosity of the soil water.

It will now be desirable to consider the effects of drought and of high rainfall on the amounts of drainage and evaporation.

The total rainfall of January and February, 1893, was above the average, and the daily records indicate that the soil of the gauges was saturated at the end of each of these months. In fact there was on March 1 a large excess of drainage (0·259 inch through 20-inch gauge) over the rainfall (0·117 inch) owing to the excess of water not having had time to percolate. During the remainder of March (2—31) the rainfall was only 0·307 inch (making a total of 0·424 inch), and of this amount 0·124 inch, or 40 per cent., percolated. The evaporation for the whole month as indicated by the difference between rain and drainage would be only 9·7 per cent. of the rain; or, when the first day is excluded, 60 per cent. This is a decidedly high amount, due in part to the very large amount of sunshine—199 hours as against the average of 118 hours (see this vol., p. 299). During the next three months there were only 2·47 inches of rain and no drainage at all. In July, 3 inches of rain fell, but owing to the dried-up condition of the soil there was again practically no drainage (0·003 inch), and even the 0·64 inch which fell in the first three days of August failed to give drainage. The soil was, however, by this time again approaching a state of saturation and on August 5, with 0·25 inch of rain, 31 per cent. (= 0·077 inch) percolated through the 20-inch gauge. From August 6 to 11, 0·166 inch of rain fell but owing to evaporation there was again no drainage, and only 10 per cent. on the 12th with 0·09 inch of rain. After a week's interval of

fine days there were four rainy days on which altogether an inch of rain fell, with, however, only 0·03 inch of drainage. In the whole month of August there were 2·38 inches of rain of which only 4·9 per cent. percolated through the 20-inch gauge and much less through the other gauges; and it was not until the middle of October that regular drainage recommenced.

The results from March 2 may be summarized as follows:

1893	Rain inches	Drainage (20-inch gauge) inches	per cent.
March 2 to July 31	5·78	0·127	2·2
" " Aug. 31	8·16	0·244	3·0
" " Sept. 30	9·30	0·244	2·6
October 1–31	4·46	2·749	61·6

The rainfall March—September was rather more than half the average amount.

Another period of drought, shorter than that just described, occurred in June and July, 1904. The rainfall of the previous months since February had been low, and in May, although 2·15 inches of rain fell, the drainage only amounted to 0·057 through 20, and 0·100 inch through 60 inches of soil. From June 1 to June 10 the rainfall was 0·155 inch and the drainage 0·035 and 0·059 inch respectively. On the 14th 0·284 inch fell, but there was no drainage. From that date to the end of the month the rain only amounted to 0·363 inch, whilst the 20- and 60-inch gauges gave 0·003 and 0·023 inch of drainage. The dry weather continued until July 25, the rain from the 1st to 24th only amounting to 0·35 inch, most of which fell on the first three days. On July 25, 1·44 inches of rain fell, and drainage was found in the cylinders of the gauges amounting to 0·217 inch in the case of the 20- and 0·185 inch in the 60-inch gauge, corresponding with 15 and 13 per cent. of the rainfall. In this case the difference between rain and drainage, 1·218 inches in the 20-inch gauge and 1·250 inches in the 60-inch gauge, would no doubt be due to a great extent to retention by the unusually dry soil. But loss by evaporation was no doubt considerable, the amount of sunshine during the month being much above the average.

With heavy rainfall in the summer we have, coincidently, high percentages of drainage, but the effect of the rapid evaporation from the soil soon shows itself. In June, 1903, after an average rainfall in May, there was a fall of 6·12 inches, of which 4·81 inches, or nearly 79 per cent. percolated through 20 inches of soil. In July, the rainfall was 4·09 inches, very considerably over the average, and the percolation

in the 20-inch gauge was 1·82 inch, or 44 per cent. In August there was again a great excess of rain (3·96 inches) and also an excess of drainage (1·35 inches), but the percentage of drainage fell to 34 per cent. All these figures are abnormally high, but they show the great reduction in the relation of drainage to rain in the summer months. In September, 1903, the rainfall was still somewhat in excess of the average (2·75 inches), whilst the drainage (0·87 inch) was quite normal for the month. The very high rainfall in October, amounting to 6·32 inches, resulted in 5·12 inches of drainage through 20 inches of soil, corresponding with 82 per cent., or about 4 per cent. more than in June with a similar rainfall.

Notwithstanding the wet condition of the soil during this period it will be seen that the amount of evaporation was, on the whole, about the same as under average conditions.

II. COMPOSITION OF THE DRAINAGE.

1. *Nitrogen as Nitrates.*

In a previous paper (this vol. p. 288) it was shown that the rain supplies annually to the soil about five pounds of nitrogen. Of this amount about four pounds represent nitrates and ammonia which would be rapidly nitrified in the soil, and the rest, about one pound, represents organic compounds which may be either more or less readily nitrified than the organic nitrogen of the soil. In any case the total amount is very small as compared with the amounts found in the drainage through the soil of the gauges.

During the last 28 years the average loss of nitrogen in the gauges has been 31·4 lbs. per acre per annum. The annual losses (see Table V) vary from year to year considerably, partly owing to differences in the rainfall and partly to the distribution of the rain. There is, in addition, as will be shown later on, a slight tendency for the nitrates to decrease, but this only manifests itself when successive averages of several years are compared. The yearly amounts of nitrogen in the drainage of the 60-inch gauge have varied from 61 to 15 lbs. with the highest recorded rainfall in 1878–9 (41·05 inches) and the lowest rainfall in 1897–8 (19·51 inches). Both years were preceded by years of high rainfall. In 1898–9 when the rainfall was, for a second year, unusually low, the 60-inch gauge lost nearly 31 lbs. of nitrogen; and in 1899–1900 nearly 38 lbs. The very low results of 1897–8 are partly due to the

complete washing-out to which the gauges were subjected the year before, when the 60-inch gauge lost 41·4 lbs. of nitrogen. It is probable, however, that the 19 years between the maximum and minimum losses have helped to increase the difference.

TABLE V.

Yearly Amounts of Nitrogen as Nitrates in the Drainage through 20, 40, and 60 inches of Soil.

Sept. 1 to Aug. 31	Rainfall	Drainage			Nitrogen, lbs. per acre		
		Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep	Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep
	inches	inches	inches	inches	lbs.	lbs.	lbs.
1877–8	32·65	14·72	16·44	14·84	44·75	39·53	45·92
1878–9	41·05	24·44	26·03	24·38	59·36	46·52	60·94
1879–80	21·36	6·89	7·39	6·50	27·03	17·87	20·19
1880–1	36·77	22·38	22·84	21·26	57·78	44·22	49·95
1881–2	32·31	15·81	16·08	14·32	32·93	31·74	35·24
1882–3	34·71	20·82	21·72	19·72	32·67	36·08	38·26
1883–4	25·77	11·86	12·00	11·21	29·31	26·85	26·89
1884–5	26·78	14·82	15·14	13·98	39·55	36·71	33·86
1885–6	31·02	17·37	18·41	16·57	34·49	32·27	34·36
1886–7	23·61	10·64	12·58	11·72	25·28	21·88	24·98
1887–8	30·50	13·96	15·58	14·67	43·10	36·90	35·67
1888–9	30·09	14·64	15·82	14·33	31·96	29·25	30·50
1889–90	27·43	13·16	13·60	12·74	27·61	24·94	28·41
1890–1	23·41	9·95	9·70	9·73	25·70	19·90	22·04
1891–2	29·68	16·50	17·43	16·47	29·39	28·45	33·43
1892–3	24·08	11·58	12·35	12·10	22·61	20·40	23·72
1893–4	29·55	13·36	14·11	14·07	40·94	31·53	34·52
1894–5	28·94	15·50	16·95	16·31	37·12	33·18	34·36
1895–6	24·37	9·84	10·75	10·35	23·18	22·77	22·78
1896–7	37·24	21·88	23·86	22·80	36·62	35·77	41·40
1897–8	19·51	5·95	6·66	6·47	18·20	13·95	15·01
1898–9	24·70	11·99	12·48	12·48	33·23	28·65	30·91
1899–1900	31·02	16·33	16·93	17·02	37·00	33·85	37·68
1900–1	24·30	10·91	12·35	11·92	33·68	28·24	29·26
1901–2	23·26	8·75	9·32	9·44	29·12	21·65	23·11
1902–3	31·25	16·33	17·09	17·59	33·70	30·98	32·73
1903–4	31·52	17·68	17·92	18·29	16·38	20·87	24·36
1904–5	25·30	10·10	10·45	10·36	23·25	21·58	22·08

The amount of water percolating through the soils of the gauges reaches its maximum, as already shown, in November, the highest rainfall being in October. The drainage then decreases until April, which is the month of minimum drainage; increases very slightly in May and June (Table VI). After a slight fall in July, the drainage again increases until November.

TABLE VI.

Monthly Amounts of Nitrogen as Nitrates in the Drainage through 20, 40, and 60 inches of Soil.

1877-8 to 1904-5	Rainfall	Drainage			Nitrogen as Nitrates per million			Nitrogen as Nitrates per acre			Nitrogen to 1 Chlorine		
		20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge
	inches	inches	inches	inches				lbs.	lbs.	lbs.			
September......	2·35	0·84	0·83	0·77	16·05	11·40	12·23	3·05	2·14	2·13	3·55	2·52	2·84
October	3·20	1·88	1·88	1·75	13·26	10·34	11·42	5·64	4·40	4·52	2·97	2·27	2·54
November	2·84	2·16	2·22	2·12	12·18	10·19	11·05	5·95	5·12	5·30	2·55	2·10	2·38
December	2·51	2·04	2·17	2·09	9·90	8 76	9·90	4·57	4·30	4·68	2·06	1·85	2·17
January.........	2·06	1·67	1·87	1·83	7·25	7·14	8·45	2·74	3·02	3·50	1·70	1·56	1·94
February	1·98	1·51	1·66	1·58	6·44	6·28	7·89	2·20	2·36	2·82	1·53	1·49	1·94
March	1·90	0·97	1·12	1·06	6·88	6·75	8·17	1·51	1·71	1·96	1·37	1·34	1·69
April	1·84	0·48	0·55	0·51	7·92	7·07	9·27	0·86	0·88	1·07	1·75	1·57	2·06
May	2·13	0·54	0·61	0·56	8·19	7·03	8·84	1·00	0·97	1·12	1·72	1·54	1·96
June	2·41	0·72	0·75	0·73	8·23	7·19	8·36	1·34	1·22	1·38	1·63	1·40	1·66
July	2·57	0·64	0·65	0·62	12·09	9·04	10·34	1·75	1·33	1·45	2·46	1·90	2·20
August	2·86	0·77	0·76	0·72	14·12	9·94	11·72	2·46	1·71	1·91	3·15	2·22	2·62
Oct.—March...	14·49	10·23	10·92	10·43	9·77	8·46	9·65	22·61	20·91	22·78	2·13	1·82	2·15
April—Sept....	14·16	3·99	4·15	3·91	11·59	8·79	10·24	10·46	8·25	9·06	2·47	1·88	2·23
Year......	28·65	14·22	15·07	14·34	10·28	8·55	9·81	33·07	29·16	31·84	2·23	1·84	2·17

The monthly results set out in Table VI show that the highest amounts of nitrogen per million in the drainage through 20 and 60 inches of soil occur in September, whilst the lowest amounts are found in February. The extremes are 16·05 and 6·44 for the 20-inch gauge and 12·23 and 7·89 per million in the deepest gauge. The amounts for the year are quite similar in the two gauges, so that the monthly differences are merely due to the mode of distribution. The soil water in the deeper gauge evidently becomes more mixed than that of the 20-inch gauge (Fig. 3).

As regards the amounts of nitrogen withdrawn from the soil in the different months, the lowest, unlike the minimum concentration, is in April. This is followed by a gradual and fairly regular rise until September, and then by a rapid rise until November, when the maximum loss occurs. This is succeeded by a fall until April.

The relation of nitric nitrogen to the quantity of the drainage is somewhat complicated. In the first place, the amount of nitrification will depend on the temperature and on the degree of moisture in the upper portions of the soil. Then to completely extract the whole of recently-produced nitrates would of course require an amount of rain more than sufficient to expel the whole of the water existing in the soil. Results of determinations of moisture made in Broadbalk soils (4) in 1869 after much rain, showed that when saturated the soil of the unmanured plot contained down to 3 feet 23 per cent. of water. This would be equivalent to about 7·6 inches of water in the soil of the 20-inch gauge, 15·2 inches in the 40-inch, and 22·8 inches in the 60-inch gauge. To completely extract the gauges would, therefore, require considerably more rain than is generally realised. The comparatively low amounts of nitric nitrogen in the drainage of the early summer months, taken in conjunction with the small amounts of drainage, indicate that most of the drainage in these months is derived from the subsoil. It is not until September that the waters richest in nitrates are obtained, whilst high results continue to be obtained throughout October and November, notwithstanding the diluted condition of the drainage at this time and the comparative inactivity of nitrifying organisms.

It will be noticed that whilst the total drainage of the 20-inch and 60-inch gauges are almost the same, that of the 40-inch gauge is distinctly higher. The total nitric nitrogen in the drainage of the 20- and 60-inch gauges also differs by rather more than 1 lb. per acre, whilst that of the 40-inch gauge is not higher, as might be expected from the higher

drainage, but about 3 lbs., or 10 per cent. lower than the mean of the other two gauges. The difference is still more marked when the

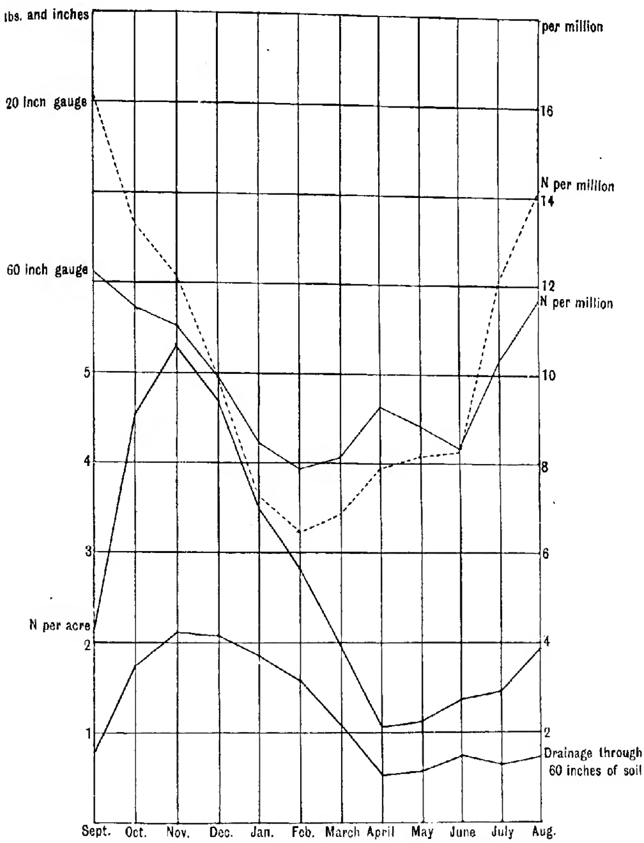

FIG. 3. Drainage through 60 inches of soil, and loss of nitrogen per acre. Nitrogen per million in the drainage through 20 and 60 inches of soil. Average 28 years.

nitrogen is considered in relation to chlorine in the three drainage waters (Table VI). The 20-inch and 60-inch gauges give almost identical results, the 40-inch gauge a much lower result (for the year).

A good example of the effect of drought on the composition of subsequent drainage is afforded by the dry period in 1893, already referred to in connection with the percolation and evaporation.

TABLE VII.

Effect of Dry Weather on the Amount and Composition of subsequent Drainage. (20-inch Gauge.)

1893	Rainfall	Drainage	Per million		Per acre		N to 1 Cl
			Nitrogen	Chlorine	Nitrogen	Chlorine	
	inches	inches			lbs.	lbs.	
April to June......	2·47	—	—	—	—	—	—
July	3·00	0·003	16·8	7·4	0·01	0·005	2·0
August	2·38	0·12	10·5	4·2	0·28	0·11	2·5
September	1·14	—	—	—	—	—	—
October...............	4·46	2·75	22·0	5·9	13·68	3·67	3·7
November............	2·93	1·84	18·1	4·7	7·54	1·96	3·8
December............	2·63	2·27	13·3	5·7	6·84	2·93	2·3

The rainfall since August, 1892, had been fairly normal with the exception of March, when the rain and drainage amounted respectively to 0·42 and 0·38 inch. The nitrates and chlorine were rather below the average, the former decreasing irregularly from 14·9 in September to 5·4 in March, the latter from 5·5 to 3·0 per million. The renewed drainage of July was probably, in view of the very high chlorine results, surface water concentrated by evaporation. In August the amount of chlorine shows that the drainage was at any rate not more concentrated than usual at this time of the year, whilst the decrease in the, still high, amount of nitric acid would indicate more subsoil water, and hence normal drainage. The next results, in October (the highest of all but two recorded for this month), clearly indicate that the water which had been near the surface during the summer months was now passing through the soil. The nitrogen then decreased until by January the drainage contained about the average amount (7·3 per million).

The only higher amounts of nitrogen recorded occurred in two consecutive months, September and October, 1887, after a year of very low rainfall (23·61 inches).

With average losses of 29 to 33 lbs. of nitrogen per acre, or deducting 5 lbs. for nitrogen contributed by rain, of 24 to 28 lbs., it would be

natural to expect some indication of a gradual exhaustion of the unmanured soil after a period of nearly 30 years. The results recorded in Table V, which gives the annual loss in each year, show, however, such wide differences, depending on the amount of rain and drainage, that it cannot be said that we have absolutely certain indication of actual or approaching exhaustion. In some of the early years the amounts of nitrogen were very large, but so were also the amounts of drainage. The following summary, giving averages for four periods of seven years, shows very little indication of a continuous falling off, especially when the amount of drainage is taken into account.

TABLE VIII.

Average Losses of Nitrogen in the Drainage through 20, 40, and 60 inches of Soil during Four Periods of Seven Years.

Harvest years Sept. 1—Aug. 31	Rainfall	Drainage			Nitrogen as Nitrates per acre		
		Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep	Soil 20 inches deep	Soil 40 inches deep	Soil 60 inches deep
	inches	inches	inches	inches	lbs.	lbs.	lbs.
1877–8 to 1883–4...	32·09	16·70	17·50	16·03	40·55	34·69	39·62
1884–5 to 1890–1...	27·55	13·51	14·40	13·39	32·53	28·84	29·97
1891–2 to 1897–8...	27·62	13·52	14·59	14·08	29·72	26·58	29·32
1898–9 to 1904–5...	27·33	13·16	13·79	13·87	29·48	26·55	28·45

TABLE IX.

Relation of Nitrogen as Nitrates to Chlorine in the Drainage during Four Periods of Seven Years.

Harvest years Sept. 1—Aug. 31	Nitrogen to Chlorine = 1		
	20-inch gauge	40-inch gauge	60-inch gauge
1877–8 to 1883–4......	2·76	2·22	2·82
1884–5 to 1890–1......	2·50	2·02	2·33
1891–2 to 1897–8......	2·12	1·73	2·06
1898–9 to 1904–5......	1·67	1·45	1·64

When, however, the nitric nitrogen is considered in relation to the chlorine, the average amounts of which in periods of several years closely resemble the averages in rain, there is distinct evidence of a decline in the amount of nitrates produced (Table IX).

Then, again, by selecting two years of heavy rainfall, each preceded by a year of low rainfall, indications of a marked reduction in the loss of nitrogen are obtained.

TABLE X.

Loss of Nitrogen in two years of High Rainfall and Drainage.

	Rainfall	Nitrogen per acre		
		20-inch gauge	40-inch gauge	60-inch gauge
	inches	lbs.	lbs.	lbs.
1880-1......	36·77	57·78	44·22	49·95
1896-7......	37·24	36·62	35·77	41·40

It is not an easy matter in view of the irregularity in the Rothamsted soils to obtain a very accurate estimate of the losses actually undergone by the soil of the gauges, and this difficulty is considerably increased by the incompleteness of the analysis of the drainage during the first seven years of the experiments. The following estimate is perhaps as correct as is possible under the circumstances.

TABLE XI.

Loss of Nitrogen in the Soils of the three Gauges during the last 35 years.

Depth of soil	Nitrogen								
	In soil and rain per acre			In drainage per acre			Remaining in soil, 1905	Loss in soil	
	In soil, 1870	In rain, 35 years	Total	1870-1877 (estimated)	1877-1905 (determined)	Total			
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	per cent.
20 in....	6027	175	6202	231	926	1157	5045	982	16·3
40 in....	10434	175	10609	204	816	1020	9589	845	8·1
60 in....	14043	175	14218	223	892	1115	13103	940	6·7

The losses of nitrogen are, therefore, considerable, but even in the case of the 20-inch gauge between eight and nine-tenths remain. It is of course possible that fixation of free nitrogen is going on all the time, and that the soil is really losing less nitrogen than indicated by the above results. We have no complete evidence either for or against fixation[1]. It is at any rate evident that plenty of nitrifiable nitrogen still remains in the soil and that the conditions remain favourable to nitrification. Determinations of lime made from September, 1896, to April, 1898, in the drainage from each gauge show that the loss of calcium carbonate amounted in a year of normal rainfall (with, however, a low amount of drainage) to about 300 lbs. in the case of the 60-inch gauge, and somewhat less in the other gauges. This would amount to 10,500 lbs. of calcium carbonate in the 35 years, or rather more than 10 per cent. of the total estimated amount[2]. There is no doubt, however, that the losses would be greater in the early years of the experiment when the soil contained more organic matter. Unlike the nitrogen, the loss of calcium slightly increases with the depth of the soil. Rather more than one-fourth to one-third of the total lime in the drainage is required to neutralise the nitric acid present.

2. *The Amounts of Chlorine in the Drainage.*

The yearly amounts of chlorine (Table XII) in the drainage are on the whole similar to the amounts found in the rain of the corresponding years, although in years of low rainfall there may be a deposition of chlorides in the soil, and consequently low amounts in the drainage, as in the year 1879–80. But the chlorides deposited one year appear as

[1] In February, 1905, two small samples were taken with a borer from the soil of the 60-inch gauge to a depth of 9 inches. The fine soil, dried at 100°, contained 0·102 per cent. of nitrogen, corresponding with 2,448 lb. per acre. This amount deducted from the estimated amount in the soil in 1870 (see p. 379) indicates a loss of 1056 lbs. in 35 years. This agrees as nearly as can be expected with the estimate in Table XI, and makes it improbable that the soil has acquired any considerable amount of nitrogen from the air, either by fixation of free nitrogen, or by absorption of ammonia, beyond that supplied by rain. It may here be mentioned that for some years, until four or five years ago, a growth of *Nostoc* was frequently observed on the surface of the 20-inch gauge. It has been shown by Kossowitsch (*Bot. Zeit.* 1894, **52**, 97) and by Bouilhac (*Ann. Agron.* 1898, **24**, 561) that bacteria exist which in presence of *Nostoc* fix elementary nitrogen. It is, however, not established that *Nostoc* is always accompanied by this microbe; and in the present case no material amount of fixation can have taken place, as the growth was always at once removed.

[2] For full results relating to calcium in the drainage through the 60-inch gauge see *Proc. R. S.* 1905, B. **77**, 14.

additional amounts in the drainage in other years, so that the averages of several years closely correspond with the average amounts in the rain for the same periods. This is of some interest, since it makes it possible in the case of field drainage, where the amount of percolation is unknown, to calculate from the concentration of the chlorine present, both the amounts of yearly drainage and the total amounts of other constituents. This applies, of course, only to conditions of soil and climate similar to those at Rothamsted. And approximately correct estimates are only to be expected when results extending over a few years are available.

TABLE XII.

Annual Amounts of Chlorine in the Rain and the Drainage through 20, 40, and 60 inches of Soil. Gain or loss of Chlorine in the Soil.

Harvest Years, Sept.-Aug.	Rainfall	Drainage: Soil 20 inches deep	Drainage: Soil 40 inches deep	Drainage: Soil 60 inches deep	Chlorine, lbs. per acre: In rain	In drainage: Soil 20 inches deep	In drainage: Soil 40 inches deep	In drainage: Soil 60 inches deep	Loss or gain in so[il]: Soil 20 inches deep	Loss or gain in so[il]: Soil 40 inches deep
	inches	inches	inches	inches	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
1877–8	32·65	14·72	16·44	14·84	11·97	15·54	17·95	15·81	-3·57	-5·98
78–9	41·05	24·44	26·03	24·38	15·73	19·83	21·05	19·37	-4·10	-5·32
79–80	21·36	6·89	7·39	6·50	10·87	5·99	6·37	5·72	+4·88	+4·50
80–1	36·77	22·38	22·84	21·26	18·06	19·00	19·40	17·49	-0·94	-1·34
81–2	32·31	15·81	16·08	14·32	15·56	12·71	13·40	11·99	+2·85	+2·16
82–3	34·71	20·82	21·72	19·72	17·49	17·40	19·19	17·09	+0·09	-1·70
83–4	25·77	11·86	12·00	11·21	14·15	12·40	12·06	11·03	+1·75	+2·09
84–5	26·78	14·82	15·14	13·98	13·32	14·83	15·57	13·76	-1·51	-2·25
85–6	31·02	17·37	18·41	16·57	12·11	12·71	14·77	13·34	-0·60	-2·66
86–7	23·61	10·64	12·58	11·72	15·98	9·33	11·08	9·95	+6·65	+4·90
87–8	30·50	13·96	15·58	14·67	16·99	19·75	20·96	18·10	-2·76	-3·97
88–9	30·09	14·64	15·82	14·33	12·59	13·20	15·50	13·99	-0·61	-2·91
89–90	27·43	13·16	13·60	12·74	10·32	11·29	12·03	11·45	-0·97	-1·71
90–1	23·41	9·95	9·70	9·73	10·56	9·86	9·86	9·67	+0·70	+0·70
91–2	29·68	16·50	17·43	16·47	15·54	14·59	15·69	14·67	+0·95	-0·15
92–3	24·08	11·58	12·35	12·10	11·16	10·04	12·21	10·51	+1·12	-1·05
93–4	29·55	13·36	14·11	14·07	18·15	18·37	17·71	16·64	-0·22	+0·44
94–5	28·94	15·50	16·95	16·31	14·74	17·80	19·48	18·83	-3·06	-4·74
95–6	24·37	9·84	10·75	10·35	13·33	10·40	11·36	10·98	+2·93	+1·97
96–7	37·24	21·88	23·86	22·80	21·19	19·61	23·21	20·93	+1·58	-2·02
97–8	19·51	5·95	6·66	6·47	16·51	7·55	8·03	7·15	+8·96	+8·48
98–9	24·70	11·99	12·48	12·48	18·09	20·10	19·26	17·36	-2·01	-1·17
99–1900	31·02	16·33	16·93	17·02	15·79	17·79	19·94	18·83	-2·00	-4·15
1900–1	24·30	10·91	12·35	11·92	16·60	19·14	17·51	14·71	-2·54	-0·91
01–2	23·26	8·75	9·32	9·44	14·80	13·99	13·99	13·32	+0·81	+0·81
02–3	31·25	16·33	17·09	17·59	17·85	22·84	25·10	24·36	-4·99	-7·25
03–4	31·50	17·68	17·92	18·29	19·65	14·70	17·98	18·77	+4·95	+1·67
04–5	25·30	10·10	10·45	10·36	15·23	14·69	14·23	13·97	+0·54	+1·00

Perhaps the most striking point in connexion with the results relating to chlorine in the drainage is the comparatively slight, although irregular, variation in the average amounts per million of water from month to month. The extremes (see Table XIII) occur in June, when

TABLE XIII.

Monthly Amounts of Chlorine in the Drainage through 20, 40, and 60 inches of Soil. Average 28 years.

1877–8 to 1904–5	Rainfall	Chlorine								
		Per million			Per acre			+ or - in rain (per acre)		
		20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge	20-inch gauge	40-inch gauge	60-inch gauge
	inches				lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
September..	2·35	4·53	4·53	4·31	0·86	0·85	0·75	+0·03	+0·04	+0·14
October......	3·20	4·47	4·56	4·50	1·90	1·94	1·78	-0·10	-0·14	+0·02
November...	2·84	4·77	4·86	4·65	2·33	2·44	2·23	-0·55	-0·66	-0·45
December...	2·51	4·81	4·75	4·57	2·22	2·33	2·16	-0·33	-0·44	-0·27
January ...	2·06	4·26	4·56	4·35	1·61	1·93	1·80	+0·13	-0·19	-0·06
February	1·98	4·22	4·23	4·06	1·44	1·59	1·45	+0·09	-0·06	+0·08
March	1·90	5·01	5·05	4·84	1·10	1·28	1·16	+0·41	+0·23	+0·35
April.........	1·84	4·51	4·50	4·51	0·49	0·56	0·52	+0·50	+0·43	+0·47
May	2·13	4·75	4·57	4·50	0·58	0·63	0·57	+0·32	+0·27	+0·33
June	2·41	5·03	5·13	5·03	0·82	0·87	0·83	-0·11	-0·16	-0·12
July	2·57	4·90	4·76	4·71	0·71	0·70	0·66	-0·11	-0·10	-0·06
August	2·86	4·48	4·48	4·48	0·78	0·77	0·73	+0·03	+0·04	+0·08
Sept.—Dec.	10·90	4·67	4·71	4·54	7·31	7·56	6·92	-0·95	-1·20	-0·56
Jan.—April	7·78	4·43	4·56	4·38	4·64	5·36	4·93	+1·13	+0·41	+0·84
May—Aug.	9·97	4·78	4·74	4·69	2·89	2·97	2·79	+0·13	+0·05	+0·23
Oct.—Mar.	14·49	4·58	4·66	4·48	10·60	11·51	10·58	-0·35	-1·26	-0·33
April—Sept.	14·16	4·70	4·67	4·59	4·24	4·38	4·06	+0·66	+0·52	+0·84
Year......	28·65	4·61	4·66	4·51	14·84	15·89	14·64	+0·31	-0·74	+0·51

the drainage from the three gauges contain respectively 5·03, 5·13, and 5·03 per million of chlorine, and in February when the minimum amounts of 4·22, 4·23, and 4·06 per million are reached. Comparing the summer and winter drainage the amounts of chlorine are practically identical in the case of the 40-inch gauge and differ only by 0·1 per million in the 20- and 60-inch gauges, the higher numbers occurring in the summer drainage. Under the circumstances it is obvious that the amounts of chlorine per acre vary directly in relation to the amount of the drainage.

Comparing the average monthly amounts per acre of chlorine in the drainage with the average quantity found during the same period of 28 years in the rain it is seen that, speaking generally, the soils of the gauges lose chlorine in the winter months and gain in the summer months. In each case there is a loss from October to December, and a gain from February to May, the greater portion of the excess occurring in March, April, and May. The greatest loss is in November, when the chlorine (per acre) in the rain is highest, and the greatest gain in April (Fig. 4).

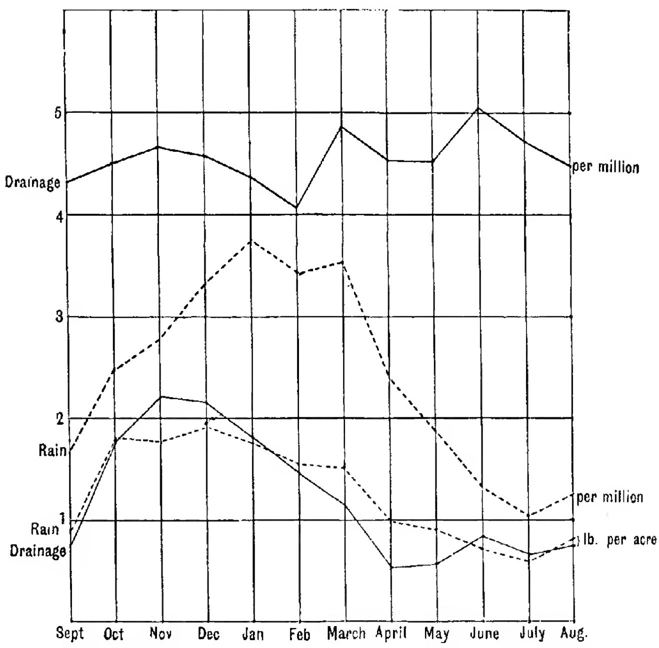

Fig. 4. Chlorine in rain and drainage through 60 inches of soil, per million and lbs. per acre. Average 28 years.

The yearly amounts of chlorine in the drainage (Table XII) are subject to great variations according to the amounts of drainage in the respective years and in that of the preceding years. In years of drought the soil may acquire several pounds of chlorine per acre from the rain (for instance, 1879–80, 1886–7, and 1897–8), whilst in wet years (1877–8, 1878–9, and 1902–3) there may be more or less considerable losses.

Calculating the total gain or loss for the whole of 28 years the following numbers are obtained:

	Chlorine lbs. per acre
20 inches of soil.........	+ 8·68
40 ,, ,, ...	− 20·72
60 ,, ,, ...	+ 14·28

From results of determinations of chlorine in samples of soil collected in 1870 near the gauges it is estimated that the soil of the 20-, 40-, and 60-inch gauges originally contained 121, 238, and 342 lbs. of chlorine per acre respectively. These amounts seem to have been washed out of the soil during the first few years of the experiments. Frankland (6) found in samples of the drainage collected in November and December, 1870, after heavy rainfall in October, amounts of chlorine varying from 21·5 to 38·0 per million. Since 1877 the highest result obtained in the monthly drainage of the 20-inch gauge (which varies the most) has been 10·0 per million.

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BRITISH TICKS.

By EDWARD GALTON WHELER,
Claverdon Leys, Warwick.

THE Ixodidae have received so little consideration at the hands of British naturalists that there does not exist amongst our literature any classification of the family having pretension to accuracy or completeness. This may be sufficient to account for the fact that in 1900 when inviting correspondence through the columns of *Science-Gossip*[1], I did not receive any reply from a fellow-countryman who had made a serious attempt to study the British ticks, though I have been favoured with much kindly assistance from correspondents who had turned their attention to foreign species.

There seems no doubt that the best classification of the genera, giving descriptions of the known species, is that contained in a very carefully compiled series of articles in the *Mémoires de la Société Zoologique de France* for the years 1896–97–99 and 1902[2]. These articles were written by M. G. Neumann, Professeur à l'École vétérinaire de Toulouse, and are entitled "Révision de la famille des Ixodidés." Some of these papers are out of print, and may not fall readily into the hands of an English reader.

The diagram (fig. 2) of the various parts of a tick may assist readers in following the descriptions in this paper.

Ticks pass through four stages in their existence: the egg, the larva, the pupa or nymph, and the adult. In the larval, pupal, and adult female stages of the sub-family Ixodinae the body is enclosed by a highly distensible cuticle. The body is partly covered by a hard scutellum, or shield, on the back, and is provided with a false head, or capitulum.

[1] Vols. VII. and VIII., New Series.

[2] Vols. IX., X., XII. and XIV.

The latter carries the palpi, and the mouth organs, consisting of a hard chitinous labium or hypostome provided with a tube for the suction of blood, and armed with rows of barbs for clinging on to the flesh of the host. On each side are situated the mandibles, also called chelifers, or chelicerae. They are retractile, and doubtless serve to cut a slot in the skin to make a passage for the insertion of the labium, and afterwards to force it into the flesh of the host. For these purposes the chelifers are furnished with a series of teeth or hooks. Collectively these organs constitute the rostrum.

The adult male is similar, but he has a shield that, with the exception in many cases of a narrow margin, covers the whole of the body. The latter is incapable of being much distended by the suction of the host's blood. In the sub-family Argasinae these shields are altogether absent and distension after feeding does not take place to anything like the same extent as with the Ixodinae. In the larval stage ticks have but six legs, but in all other stages eight legs.

In adults the sexual organ is situated far forward between the haunches of the legs; behind it is the anus, usually surrounded in part by a groove, and on each side, near the fourth pair of legs, is placed a stigmal plate or peritreme for respiration, in the centre of which is the stigma. The plates are absent in the larval state. There is reason for believing that the sexual organ of the male may be either immature or obsolete in certain, if not all the species of Ixodidae, and that in such cases the sexual functions are performed by the mouth organs, all of which are inserted with the exception of the palpi[1]. The sexual orifice is absent in the larval and pupal stages. The tarsus, or last joint, of the first pair of legs is furnished with a peculiar organ (see figs. 2, 13 and 14), known as "Haller's organ," which is probably one of touch, hearing, or smell; but its function is not understood. The second pair of legs are the shortest, and the fourth pair the longest.

The life-history of a tick is sharply divided between a free and a parasitical existence. In the first state it lives absolutely without food of any sort for prolonged periods, and passes its time either in a semi-torpid condition, or else is actively occupied in searching for a host on which to establish itself. A headless female of *Ixodes ricinus*[2], lacking all the mouth organs by which feeding would be possible, survived under my observation for over a year in captivity, and was eventually lost.

[1] See Appendix, p. 425.

[2] Mentioned by me in "Louping-ill and the Grass-tick" in the *Royal Agricultural Journal* of December, 1899 (Vol. x., Part IV.). See Appendix, p. 427.

Argas persicus is similarly stated to have lived without food for three and a-half years in captivity[1]. At such times all growth is suspended, and the tick is debarred from making any advance towards metamorphosis from one stage of its existence to another.

In the parasitical states life is supported by sucking the blood of the host until the body of the tick has, unless it is an adult male, become enormously distended, and it is in this condition that these pests are generally noticed owing to their increased size. When replete, whether as larvae or nymphs, most species fall to the ground, and there remain while development is proceeding inside the distended cuticle. After a time the skin is split open, and the creature emerges with its rostrum, shield, legs and other external parts, increased in size and fully developed. The body is proportionately diminished, so that the animal's entire length is about the same as before; but the new body, being formed of a similarly distensible cuticle, is again ready for repletion so soon as another host is attacked. Adult females when distended also fall to the ground, and remain there for oviposition.

Some species never leave the host they have first found, but pass all their metamorphoses upon it. In this respect the habits of different Ixodidae vary considerably. *Ixodes ricinus* seeks a fresh host after each moult, but as yet little is known of the habits of any other British species. Mr Lounsbury, Government Entomologist at the Cape of Good Hope, informs me that the "red tick," *Rhipicephalus evertsi*, passes the first moult on, and the second moult off, the host. *R. decoloratus*, the "blue tick," never leaves the host that it has once found, after being hatched out of the egg, until, if a female, it is ready in its turn for oviposition. *Argas persicus* attacks by night, like the bed bug, a practice which may enable it to escape destruction from the beaks of the fowls or pigeons which are its usual prey, as at such times they would be asleep, or at least in a drowsy condition. Mr Lounsbury says "it has the peculiarity of undergoing an additional moult, and, what is more, when adult, alternates egg-laying with feeding, the interval being about the same as between the moults." Referring to the South African "bont-tick," *Amblyomma hebraeum*, Mr Lounsbury writes: "Females do not appear to complete their engorgement until they have mated." If this be so with *I. ricinus*, and perhaps other species, it may account for the numerous dead and half-distended specimens that may generally be found on sheep in the North of England.

[1] Referred to by C. Fuller in his *Bovine-tick Fever*, 1896, p. 8.

The length of life depends mainly on the climatic conditions, and whereas Messrs Dixon and Spreull state that *Rhipicephalus decoloratus*, the Texas cattle-tick, is only sixty days in passing the whole period of its existence, it is probable that our British species average about a year and a half, varying largely according to circumstances.

The damage done to stockowners by these pests in other countries is enormous. Mr Cooper Curtice says[1]: "Cattle-ticks cause the quarantine of eighty-one counties in North Carolina. The cattle traffic in thirteen States and the Indian Territory is seriously interfered with on account of the ticks."

Mr P. R. Gordon, Chief Inspector of Stock for the Government of Queensland, states in his Annual Report for 1898 that previous to that year no less than £44,000 had been spent in that colony in connexion with the investigations and experiments made in combating "tick," or "Texas fever." The searching character of these investigations has probably proved the salvation of stock-raising in Australia, as they resulted in the discovery, by Mr C. J. Pound, Director of the Stock Institute, that inoculation by the blood of immune beasts would produce immunity in previously susceptible stock.

From Cape Colony Mr Lounsbury writes in his Report for 1899: "Heartwater," another tick-inoculated disease, "seems to have gained fresh impetus of late years, and is spreading by leaps and bounds into the Midlands." "The market value of these properties is depreciated by the infection from 30 per cent. to 60 per cent., I am reliably informed." This disease attacks sheep and goats, and is carried by a tick named *Amblyomma hebraeum*.

The following diseases are now known to be tick-conveyed, the tick acting as an intermediary host[2]:

Human Tick Fever	Man	*Ornithodoros moubata* (? *savignyi*)
Texas Fever or Redwater	Cattle	*Rhipicephalus annulatus* " *decoloratus* " *evertsi*
Heartwater	Sheep, goats, etc.	*Amblyomma hebraeum*
Malignant Jaundice	Dogs	*Haemaphysalis leachi*
Piroplasmosis	Sheep	*Rhipicephalus bursa*
Piroplasmosis	Cattle in Europe	*Ixodes ricinus* (?)

1 "Regulations for the Control of Contagious Diseases of Live Stock, etc.," May 1st, 1900, North Carolina Department of Agriculture.

2 See Nuttall (1904-5) *Journal of Hygiene*, Vol. IV. pp. 219—257; Vol. V. p. 237, *et seq.* *Trans. Epidemiol. Soc.* London, Vol. XXIV. pp 12—32. This author is preparing an exhaustive treatise on Ticks.

The ravages caused in Scotland and the Borders by the disease known as "Louping-ill" have been commonly attributed to the direct agency of the Grass-tick, *Ixodes ricinus*, but recent investigations negative this conclusion, except as to its being an accidental carrier of the specific bacillus[1].

That ticks may be the carriers of the germs of other animal diseases in this country is very probable.

As the study of ticks is of so much economic importance, a few hints as to the methods of collecting and preserving them may not be out of place. The object in view is usually identification of species, or investigation of the life-history of the parasite. For the former purpose the large distended females, which are generally those first noticed on the host, are of comparatively little use. The great distension of body obliterates some material characteristics and obscures others. Where these large females are observed careful search should be made for the much smaller undistended specimens, by which identification is facilitated.

Ticks of a uniform brownish colour may generally be preserved without damage in spirits of wine, but those having variety of colour should be immersed in 3 per cent. formalin. For examination and future reference I find it convenient to mount them dry in cells as microscopic objects. This keeps them clean and free from dust. Those that have been soaked in formalin must be very thoroughly washed and dried. Even then they will be found to deposit an oily dew on the slide and cover-glass. This can only be removed by remounting, which may have to be done more than once. Treated in this manner they have so far retained their colours excellently. They may also be mounted in Canada balsam as transparent objects, but so mounted they are far harder to identify, and I have found difficulty in clearing the body of its contents when preparing them in this manner after they have been much distended. Ticks may be almost instantly killed by the use of chloroform.

For the purpose of studying their life-history ticks may be kept alive for long periods in tightly corked glass bottles, but many species require to be supplied with a little very slightly damped sand and fresh moss. Provided there is enough moisture to keep the moss alive, and no more, lest the ticks become mouldy, they will survive many months. Air does not seem necessary to them. If collected when fully distended

[1] The results of the investigations of the Louping-ill and Braxy Committee of the Board of Agriculture, which are here referred to, will shortly be published in a Blue Book.

in any immature stage they will undergo metamorphosis, or when adult the females will lay eggs, in confinement.

The process of egg-laying by ticks is most remarkable, and was fully described by Mr R. T. Lewis in the *Royal Microscopical Journal* of 1892. When oviposition is about to take place, the head is depressed till it rests close against the under side of the body (fig. 4). In this attitude the end of the rostrum actually touches the genital orifice, the palpi being at the same time widely opened out. From between the head and the shield a white, perfectly transparent, delicate, gelatinous membrane is brought down over the head, which it temporarily conceals. This is attained by inflation with a transparent fluid. The end of this membrane terminates in two points, covered with a glutinous secretion. At the same time a semi-transparent ovipositor is pushed forward from the genital orifice. As the ovipositor, within which is the egg, projects, this organ turns inside out, and leaves the egg protruded at the end, lying between the two conical points of the membrane. The ovipositor and membrane are then both withdrawn from each other, leaving the egg adhering to the glutinous surface of the latter. Owing to the withdrawal of its fluid contents the membrane collapses, and, dragging the egg forward with it, deposits it on the top of the head. Neither the legs, palpi, nor the organs of the mouth take any part in the oviposition. After the collapse of the membrane the palpi are closed, and the head is raised, by which latter action each egg is pushed further forward to the front edge of the shield, forming in time an adherent mass of eggs, which are deposited in front of the tick (figs. 1 and 5). The rough sketches shown on fig. 3, *a*, *b*, *c*, and *d*, will help to explain the process. The time occupied by a female *Ixodes ricinus* in depositing one egg was three minutes, with a further similar interval between the laying of two eggs. As the number of eggs laid is about 2,050[1], and the process continues at intervals for several days, it may easily be observed under the microscope.

It is scarcely necessary to emphasise the importance of keeping notes of the date and place where specimens are found, together with any circumstances attending their capture, especially the prevalence of disease amongst hosts infested by them.

It must be remembered that not only do individuals of all species vary much in size when fasting, but in the Ixodinae the variation is

[1] Some foreign ticks, such as *Amblyomma hebraeum*, are said to lay as many as 17,000 eggs. Fig. 1 is from a remarkable photograph by Mr C. J. Pound of female Rhipicephali (a foreign species) ovipositing.

immensely increased when distension takes place on a host. Full consideration must be given to this fact when referring to the measurements given below. The colours of distended individuals also depend entirely on the quantity of blood consumed. When the distension is complete the colour is usually a blue-black in all stages.

It is with the object of popularising the systematic study of British ticks that I venture to print the following *résumé* of M. Neumann's classification, giving copies of such of his figures as may assist in explaining the letterpress[1]. The descriptions which are in great part taken from those of M. Neumann, are confined to the more salient characteristics, and may probably suffice for identifying the sub-family and genus to which a specimen may belong. To these are added remarks on the number of known species in each genus, a description of those which have been identified in this country, a list of synonyms, and other points of interest[2]. Most of the characteristics referred to are such as may be examined readily without having recourse to any more powerful magnifier than a pocket lens.

I am indebted to the Editor of the *Royal Agricultural Society's Journal* for kindly lending me the blocks of figs. 11, 16, 17, 18, and 19, and the Editor of the *Highland Agricultural Society* for that of fig. 38, all of which were reproduced from my photographs.

CLASSIFICATION.

The family of the Ixodidae are broadly divided into two sub-families—I. Argasinae; II. Ixodinae.

I.—THE ARGASINAE.

The Argasinae are plainly distinguishable from the Ixodinae by the absence of either dorsal or ventral shields in either sex, also by the situation of the rostrum, this being placed beneath the cephalothorax, which covers it as with a hood, except in the larval state, when it is often terminal. In the pupal state it often partially projects. The palpi are plain, cylindrical, and the joints differ little from each other. Legs nearly equal in length. Colour varying from earthy yellow, or red, to dark brown. Sexual orifice situated between the two first pairs

[1] The illustrations copied are figs. 12, 15, 27, 29, 30, and 35.

[2] My remarks are based upon a series of notes contributed to *Science-Gossip* in 1900 and 1901.

of legs. In general dimensions the male is smaller than the female. Distension, after feeding, moderate.

The genera of the Argasinae are (*a*) *Argas*; (*b*) *Ornithodoros*.

GENUS *ARGAS* Latreille, 1796.

Synonym *Rhynchoprion* Hermann, 1804.

Body flat, general contour round or oval: narrower in front than behind, and larger behind the haunches of the fourth pair of legs. The sides of the body thin, or slightly thickened like a cushion. Tegument of body finely shagreened, except in certain spots which are covered with thin, roundish discs, more or less numerous and variously situated: the most important always forming a radiating series, of which the central one is longest both on the back and beneath. Eyes absent.

Of this genus M. Neumann describes eleven species, some of which are doubtful. Of these *Argas reflexus* and *A. vespertilionis* have both been found in England.

Argas reflexus Fabricius.

Synonyms: *Acarus reflexus* Fabricius, 1794; *Acarus marginatus* Fabricius, 1794; *Argas reflexus* Latreille, 1796; *Rhynchoprion columbae* Herm. 1804.

Adults: length, female from 7 mm. fasting, to 8 mm. when distended, (fig. 6); male, 6 mm. (fig. 7). The thin tegument of the female allows the brown or dark violet tint of the digestive organs to be seen, the margin always remaining yellowish (*marginatus*) and a little raised (*reflexus*) when fasting. The male is uniformly brown. The tarsi of all the legs have a prominent dorsal knob at the extremity. The hypostome is rounded at the end, and often a little dilated in the middle. Dorsal surface of the body finely shagreened. The discs are larger towards the centre and smaller and more numerous within the margin. The latter is finely and evenly folded, or wrinkled all round the body. Two of these, which are large, oval, and divergent in front, are situated near the middle line, about one-fourth of the distance from the front. They are surrounded by an interrupted circle of smaller ones. Posteriorly are others radiating from the centre, with one long middle line of this series, which almost reaches to the centre. On the ventral face is a similar well-defined radiating series. The male closely resembles the female, but the former is more narrow in front[1].

The nymph resembles the male, but is without the sexual organ.

[1] Compare fig. 7 with that of *A. persicus*, fig. 39.

The larva is round, 2 mm. in length, and has the rostrum terminal. The three pairs of legs are relatively long.

In this country this species has been found in Canterbury Cathedral, but is common abroad[1]. It is parasitical on fowls and pigeons, which it only attacks by night, hiding itself in the daytime.

Argas vespertilionis Latreille.

Synonyms.—*Carios vespertilionis* Latreille, 1796. *Caris vespertilionis* Latreille, 1804. *Argas fischeri* Audouin, 1827. *Argas pipistrellae* Audouin, 1832. *Caris vespertilionis* Gervais, 1844. *Caris elliptica* Kolenati, 1857. *Caris longimana* Kolenati, 1857. *Caris decussata* Kolenati, 1857. *Caris inermis* Kolenati, 1857. *Argas fischeri* George, 1876. *Argas pipistrellae* Westwood, 1877.

Adult. Length, 3·70 mm. by 3·78 mm. wide. Body nearly round.

Dorsal surface surrounded by a margin formed of somewhat regular folds, and shagreened within. A deep transverse integumental fold behind the anus, which is situated about the centre of the body. Rostrum covered by the hood. Hypostome with four rows of teeth, and about six in each row. Palpi claviform. Legs thick, cylindrical; tarsi truncate; coxae in contact with each other (figs. 8 and 9).

Nymph. Rostrum partly exposed. Length, fasting, 1·40 mm. by 1·10 mm. Neumann gives the measurements of the nymph as 2·40 by 2·10 mm.

Larva. Similar, but rostrum fully exposed. Length, partly distended, 1·10 mm.

The above descriptions are taken from two mounted specimens kindly lent to me by Mr H. E. Freeman, being some of the original individuals found at Blyborough in 1877 when removing the church roof, and described in *Science-Gossip*[2]. It is parasitical on bats.

GENUS *ORNITHODOROS*.

Body with thick sides, often densely covered with small, round, shining granules in various patterns, some deep furrows beneath. Eyes sometimes present (?).

The larva of one species, *Ornithodoros moubata* (? *savignyi*), has been shown to pass the whole of that stage of its existence in the egg, and to hatch out as a nymph[3].

[1] *Science-Gossip* (Old Series), Vol. x., 1874.

[2] *Science-Gossip* (O.S.) Vol. XIII., p. 104, and in the *Quekett Microsc. Journal*, Vol. IV., p. 223. Also (N.S.) 1901, where the illustration is called the nymph, in error, as is shown by the context.

[3] *The Nature of Human Tick Fever*, by Dr J. L. Todd, 1905.

No indigenous British species, but the following has been imported:

Ornithodoros megnini Dugés.

Synonyms: *Argas megnini* Dugés. *Rhynchoprion spinosum* Marx.

Nymph. Length, 3 mm. to 4 mm. fasting, to 9 mm. when replete.

Body brown, diamond-shaped, and with the rostrum exposed before repletion. Rostrum beneath body, and the latter squarer after distension. Palpi filiform. Legs far apart, and coxae almost entirely concealed beneath the skin. Surface of anterior half of body covered with small brown spines, replaced by whitish hairs posteriorly, which are specially numerous in the hinder margin. The stigmata are placed above, instead of behind, the fourth pair of legs. These differ entirely from the stigmal plates and peritremes usually present, and consist of cone-like projections pointing backwards. The top is truncate, and perforated by an orifice. Through this is a jointed organ, somewhat resembling the terminal joints of the palpi, which partially fills the orifice, and is furnished with three hairs at the end. It can be projected and withdrawn with rapidity. Its use is unknown. This peculiar feature, which, according to Neumann, is absent in the adult, may suffice to cause this species to be relegated to a separate genus.

The female is stated by Neumann to differ greatly from the nymph, which latter attains dimensions at least as large as the mature adult. It is in this state that it acquires most of the reserves of blood, which the female utilises to form its eggs.

Two specimens in the nymphal state were taken from the ear of an American visitor to Cambridge by Dr J. Christian Simpson[1]. They were supposed to have entered the ear when the American was camping out in Arizona. This species is well known in the States as infesting the ears of children and animals[2].

II.—IXODINAE.

The Ixodinae have the rostrum terminal, and never concealed under the body. Palpi four-jointed, of which the fourth is very short, and is situated in a hollow at the end of the third. Legs somewhat unequal in length. They are six-jointed, with two false joints, giving the appearance of having eight joints; one being on the femur and the other on the tarsus of each leg; but the latter is absent on the front pair.

[1] See his description with illustrations in the *Lancet*, April 27, 1901.

[2] See *New York Ent. Soc. Journ.* for 1893, pp. 49 to 52.

The cuticle of the body is very distensible in all stages, except in the case of adult males, and covered more or less, according to the state of distension at the time, by a dorsal shield, or scutellum. This shield seldom or never covers so much as one-half of the body, and as distension takes place it is proportionately less. In the case of males, which do not distend, the body is entirely covered, or with the exception of only a narrow margin. Stigmata are encircled by peritremes situated behind the haunches of the fourth pair of legs. The sexual orifice is situated beneath, between the haunches of the first three pairs of legs. In both sexes the orifice is half encircled by a groove, opening outwards behind (see fig. 11). There is considerable difference between the sexes, the males being usually the smaller. There are often eleven indentations on the posterior margin. The dorsal base of the rostrum of the female has two symmetrical hollows, with numerous punctuations, which are not found in the males, nymphs, or larvae; their purpose is doubtful.

The Ixodinae are chiefly parasitical on mammals, but also attack birds and reptiles. They rarely confine themselves to one species of host.

The genera of the sub-family of Ixodinae are:—

Ixodae, comprising *Ixodes, Eschatocephalus, Aponomma, Hyalomma, Amblyomma.*

Rhipicephalae, comprising *Rhipicephalus, Haemaphysalis, Dermacentor.*

IXODAE.

The Ixodae are distinguished from the Rhipicephalae by the length of the rostrum, which reaches nearly to the end of the palpi, sometimes further. The palpi are longer than broad. The presence or absence of eyes divides the genus into two groups:—*Amblyomma* and *Hyalomma* have eyes, which are placed on the marginal edge of the shield (fig. 10). *Ixodes, Eschatocephalus* and *Aponomma* have no eyes.

The form of the anal groove gives another division. In *Ixodes* and *Eschatocephalus* this groove contours the anus in front and opens behind (fig. 11). In *Ceratixodes* this groove is present in the male, absent in the female. In *Aponomma, Amblyomma,* and *Hyalomma* it contours the anus behind and is open to the front (fig. 12).

There is close affinity between *Ixodes* and *Eschatocephalus*; in fact, there is no fundamental characteristic to separate the females of the two genera; the great length of the legs, a deflected direction of the

rostrum, and the habit of living in holes and caverns, alone give presumption for placing a female specimen in *Eschatocephalus* rather than *Ixodes*. The males, however, differ entirely in the form of their palpi, which, flat and caniculated on the inner margin in *Ixodes* (fig. 13), are boldly claviform in *Eschatocephalus* and *Ceratixodes* (fig. 15).

The affinity between *Aponomma*, *Amblyomma*, and *Hyalomma* is greater still. The absence of eyes, as in *Aponomma*, appears a character easily distinguishable; but in some of the *Amblyomma* to find the eyes requires extreme attention, as they are neither prominent nor distinct in colour. In such cases they are probably immature or obsolete.

There is no definite distinction between the females of *Amblyomma* and *Hyalomma*, but it is otherwise with the males, which in *Hyalomma* are provided with ad-anal shields (fig. 12). These are wanting in *Amblyomma*.

(A) ANAL GROOVE ENCIRCLING ANUS IN FRONT.

(a^1) *IXODES* Latreille, 1795.

Synonyms: *Acarus* Linn., 1758; *Cynorhaestes* Hermann, 1804; *Crotonus* Dumeril, 1822.

Eyes absent. Palpi long. An ad-anal groove open or closed behind, encircles the anus in front; another long groove similarly encircles the sexual organ in front and widens behind (fig. 11). No terminal spine to the tarsi. Underside of the male covered with shields or plates. Dorsal shield of male covering the whole body with the exception of a margin. No indentations on the posterior margin. The distended female has three dorsal longitudinal grooves behind. Peritremes and stigmata circular.

Professor Neumann describes over sixty species of this genus.

Ixodes ricinus Latreille, 1804[1].

Synonyms: *Reduvius* Charleton, 1668; *Ricinus caninus* Ray, 1710; *Acarus ricinoides* De Geer, 1778; *A. ricinus* Linnaeus, 1788; *Cyno-*

[1] In the original article in *Science-Gossip* (Vol. VIII., p. 39) the name of *Ixodes reduvius* Leach, was adopted, following Neumann's classification. He now points out in his fourth Mémoire that this is an error, as Leach was describing a different parasite. The name *reduvius* should be therefore deleted, and *Ixodes ricinus* Latreille, substituted. This species is locally known as the "Grass-tick" in the North of England, and is one of the commonest British species.

rhaestes reduvius Hermann, 1804; *C. ricinus* Hermann, 1804; *Ixodes megathyreus* Leach, 1815; *I. bipunctatus* Risso, 1826; *Cynorhaestes hermanni* Risso, 1826; *Crotonus ricinus* Dumeril, 1829; *Ixodes trabeatus* Audouin, 1832; *I. plumbeus* Dugés, 1834; *I. reduvius* Hahn, 1834; *I. fuscus* Koch, 1835 (?); *I. lacertae* Koch, 1835 (?); *I. pustularum* Lucas, 1866; *I. fodiens* Murray, 1877; *Ixodes rufus* Koch; *Ixodes sulcatus* Koch; *Ixodes scuiri* Koch.

FEMALE (fig. 17). Length from about 3 mm. when fasting, to 10 mm. long by 6·50 mm. wide when fully distended. Basal joint of first pair of legs with a long spine. Legs, shield, rostrum, etc., dark brown to nearly black. Colour of body deep orange-red, showing four faint dark intestinal lines behind the shield; lighter underneath; light grey in front both above and below. Pubescent, opaque, and margined. When distending, light red to reddish-grey, or even pure white; fully distended, olive green, or dark red to black, with irregular yellow streaks on the back and sides when about to lay eggs. Sexual orifice opposite fourth pair of legs. MALE (fig. 16). Length about 2·35 mm. to 2·80 mm. Coxae of first pair of legs with shorter spine. Body dark brown to almost black, with brownish-white margin. Apparent sexual orifice opposite third pair of legs. Rostrum much shorter than that of female (figs. 13 and 14). Shield oval. Anal shield small, about one-third the length of the large ventral shield (fig. 21)[1].

NYMPH (fig. 18). Length, about 1·50 mm. fasting to 3·00 mm. when replete. Body olive-white, with four distinct brown posterior intestinal marks, also similar anterior ones; leaving a paler centre to the shield shaped like an arrow-head. When distending, opaque white to blue-black, and finally black.

LARVA. Length, 0·80 mm. fasting to 1·43 mm. distended. Body transparent, with olive-green intestinal marks; same colours as nymph when distending (fig. 19).

It is parasitical on numerous hosts, of which the favourite appear to be sheep, goats, cattle, and deer; but it is found on hedgehogs, moles, bats, etc., even on birds and lizards.

Ixodes hexagonus Leach, 1815.

Var. *longispinosus* Neumann.

Synonyms: *I. autumnalis* Leach, 1815; *I. erinacei* Audouin, 1832; *I. reduvius* Audouin, 1832; *I. crenulatus* Koch; *I. vulpis* Pagenstecher, 1861; *I. erinaceus* Murray, 1877; *I. ricinus* Mégnin, 1880.

[1] Compare figs. 21 and 22.

FEMALE (fig. 20). Length, 3·00 fasting to 11 mm. when fully replete. Coxae of first pair of legs with a moderate spine. Shield heart-shaped, punctate; body finely hirsute. Palpi short and broad. Labium shorter, and tarsi of all legs more truncate than in *I. ricinus.* Body when slightly distended drab, waxy, and semi-transparent. Rostrum, shield, legs, &c., light testaceous. MALE. Length, 2·50 to 3 mm. Red-brown, legs lighter. Shield punctate, leaving a narrow margin round the body. Genital orifice opposite the interval between the second and third pair of legs. Body elliptical, almost as large in front as behind. Spine on coxae of first pair of legs longer than in the female, but shorter than that of the male *I. ricinus.* Anal shield nearly as long as the ventral shield between the apparent sexual orifice and the anus[1] (fig. 22).

PUPA. Fasting 1·76 mm. Body light bluish-grey, margined, transparent, with four posterior large intestinal marks joined together behind the shield, and smaller ones extending to the front and sides; visible through the shield. Uniform brownish-white when distended. Shield. legs, rostrum, etc., pale testaceous.

LARVA. 0·88 mm. fasting to 1·76 mm. distended. Body light, translucent, becoming dark on repletion. Shield, legs, etc., very pale testaceous. Body with very similar intestinal marks to *I. ricinus.*

This species is common, and is parasitical on various hosts, more especially on stoats, ferrets, hedgehogs, etc. It is also found on sheep, cattle, and other animals. The males are rare, and, unlike *I. ricinus,* are not generally found accompanying the female on the host. It seems possible from this fact, that this species is essentially a "kennel" tick, frequenting naturally those animals only that return nightly to a kennel, hole, or burrow, at which time sexual intercourse may take place, and that when found on other animals its presence may be considered accidental, and that in such cases propagation of the species is unlikely to occur. The point seems worthy of investigation.

Ixodes hexagonus Leach, var. *inchoatus* Neumann, described as *I. plumbeus* in *Science-Gossip* of 1899. The length of the female is only about 2·86 mm. fasting to 6·56 mm. when replete. Colour of body fasting light brownish-grey, with eight large dark triangular intestinal marks, terminating within the margin, two other small ones being nearly concealed by the shield. Margin distinct, grey. Head, shield, legs, etc., same colour as *I. hexagonus.* Coxae of first pair of legs differ, having

[1] Compare figs. 21 and 22.

no distinct spine, but sometimes a tubercle. The second and third pairs have also small tubercles. Labium shorter, with only eight barbs, as against about ten on the outer margin in *I. hexagonus*. MALE. Length, 2·52 mm. Body elliptical, deeply punctate above and below. Margin round shield wider than in *I. ricinus*. Apparent genital orifice as in *I. hexagonus*. Small spine or tubercle on coxae of front pair of legs. Anal shield long as in *I. hexagonus*. This description is taken from a solitary capture found in the North Tyne Valley in copula, intercourse being by the mouth organs, as with *I. ricinus*.

PUPA and LARVA. Similar to *I. hexagonus*, but smaller and lighter, the larva, being 0·74 mm. fasting. This tick is very abundant on the shepherds' dogs on the Border, but in no case was found on sheep. The male was not found present with the females on the host.

Ixodes tenuirostris Neumann.

The following description is taken from one of two females found on a vole at Painswick, in Gloucestershire, in 1893, kindly sent me by Mr C. J. Watkins, who also gave me photographs of a nymph and larva, evidently of the same species, from the collection of the Hon. C. Rothschild. Both the females have been mounted in balsam. The one is in my possession; the other is in the British Museum. I found two females of this species on a field vole, at Alnwick, on August 18th, 1901.

FEMALE. Length partly distended 3·78 mm. Coxae of all legs without spines or tubercles. Palpi long and narrow, second joint twice the length of the third joint. Capitulum prolonged laterally to a prominent point on each side (fig. 23), from near the ends of which spring the palpi, which are thus set widely apart at the base. Coxae of fore-legs developed to fit into the angle thus produced. Shield oval, with two posterior marginal indentations. Sexual orifice between the third pair of legs. Tarsi of fore-legs cylindrical, truncate, and with very slight indentations. Body finely and shield coarsely and sparsely punctate.

MALE (fig. 24). Length 1·83 mm. Light brown, margin lighter, nearly white. Capitulum slightly distended laterally. Palpi wide apart at the base, though in less degree than in the female. Coxae of all legs without spines or tubercles. Apparent sexual orifice opposite the space between the second and third pairs of legs. Ventral shield large. Tarsi short and truncate. Labium and palpi very short and wide.

The male was described for the first time by me in *Science-Gossip* for December, 1901. I was indebted to Mr Pocock, of the British Museum, for kindly lending me a specimen preserved in spirits, recently taken from a long-tailed vole (*Arvicola pratensis*) near Swansea. The species occurs on the short-tailed vole (*A. agrestis*), and doubtfully on the water vole.

As it has now been taken in Gloucestershire, Northumberland, and in South Wales, it must be widely distributed, and will probably prove to be by no means uncommon. This species is the most minute of the British ticks. It resembles *I. hexagonus* in general appearance, but is much smaller, and can be at once recognised by the greater width between the palpi at their base than at their extremities, which touch, and thus give the idea of grasping, the labium. All the above specimens were taken from voles. I also found a fasting nymph on a dead shrew mouse at Alnwick in July, 1902. Length 1·10 mm. Very transparent. Light testaceous mottled with brown. Shield coarsely and body finely striated above. A few strong white hairs above and below. The lateral projections of capitulum marked.

(B) ANAL GROOVE ABSENT IN FEMALE, BUT ENCIRCLING ANUS IN FRONT IN MALE.

(a^2) *CERATIXODES.*

Synonyms: *Ixodes* Cambridge, 1879. *Hyalomma* Cambridge, 1879. *Ceratixodes* Neumann, 1902.

Palpi long, convex inside and with a conical prolongation in the male, slightly caniculated and swollen at the end in the female. No eyes. Anal groove absent in the female, but present in the male. One anal and two ad-anal shields in the male. Peritremes circular in both sexes.

Ceratixodes putus Cambridge.

Synonyms: *Ixodes putus* Cambridge, 1879; *Hyalomma puta* Cambridge, 1879, female. *Ixodes borealis* Kramer and Neumann, 1883, female. *Ixodes fimbriatus* Kramer and Neumann, 1883, male.

FEMALE (fig. 25). Length fasting 3·30 mm. to 10 mm. when replete. Body oval, rounded at both ends, light grey, with numerous white hairs above and below. Shield yellowish-grey mottled, with lateral triangular margins rich brown; subtriangular in shape, and twice as wide in front

as behind, where it is rounded. Cervical grooves converging in front, then diverging and a little concave within, enclosing a raised portion: punctuations large and fairly regular. Sexual orifice opposite the second pair of legs. Sexual grooves widely separated behind. Anal grooves absent. Peritremes round. Legs and palpi light green, mottled with dark green and orange. False articulations near the middle of the tarsi of the three hinder pairs of legs. Labium orange, with two rows of teeth on each side.

MALE (fig. 26). Length 3·70 mm. Body greenish-yellow, mottled with black when alive, margins light grey. After death, body dark reddish-brown. Flat, square, and covered with both large and small punctuations. The margin divided behind into five short wide segments or festoons, on each of which is a fringe of strong white bristles. Ventral side finely punctuated, showing the same five segments which are separated from each other by the sexual and anal grooves respectively. Apparent sexual orifice opposite the space between the first and second pair of legs. Sexual grooves widely diverging behind, anal grooves parallel. Peritremes small and round. Palpi much longer than labium, third joint being as long as the first and second together, and pointed. Legs and palpi yellowish-green mottled with darker green. Labium bright orange, very short. Three front pairs of legs thick, the third being thicker than the second, and the second than the first. The fourth pair much attenuated.

NYMPH. Length 1·59 mm. to 3·50 mm. when fully distended. Colour (in spirits) brownish-yellow. Body nearly round. When fully distended nearly black, and legs dark testaceous. Shield shaped like that of the female.

This species had not been reported in England till 1901, when I received three distended nymphs found on a guillemot from Mr S. F. Harmer, F.R.S., University Museum of Zoology, Cambridge. Mr Pocock afterwards obtained a number of distended females from a dead puffin at Morthoe in North Devon. Since then a considerable number of males and females, both fasting and distended, have been taken by Mr Hewett of York, on cliffs frequented in the nesting season by guillemots, and other sea birds, at Bempton and Buckton on the Yorkshire coast. These were under small stones on the narrow ledges of cliff facing the sea, and in some cases were in copula. I have myself found a few on the Pinnacle rocks on the Farne Islands. I have also received a specimen from the Hebrides. It is widely distributed, having been found as far north as Alaska, and as far south as Cape Horn. The

male is certainly the most remarkable in appearance of the British ticks.

(a^3) *ESCHATOCEPHALUS* Frauenfeld, 1853.

Synonyms: *Haemalastor* Koch, 1844; *Sarconyssus* Kolenati, 1857.

Rostrum long; palpi claviform (fig. 15) in the male, flat and caniculated in the female. Ad-anal groove contouring anus in front and open behind. Peritremes circular. Irregular chitinous thickenings both above and below in the male. Very fine striae or parallel grooves on the female. Legs generally very long.

Seven species of this genus are described. They are mostly parasitical on bats, and inhabit holes and caverns.

One species, *E. vespertilionis*, widely distributed on the Continent, has just (January, 1906) been received by me from Mr Newstead of the Liverpool University, having been collected by him at Cefn in Wales.

Eschatocephalus vespertilionis (C. L. Koch).

Synonyms. Male. *Eschatocephalus gracilipes* Frauenfeld, 1853; *Ixodes troglodytes* Schmidt, 1853; *Sarconyssus kochi* Kolenati, 1860; *Eschatocephalus frauenfeldi* L. Koch, 1872; *Eschatocephalus seidlitzi* L. Koch, 1872; *Ixodes longipes* Lucas, 1872; *Ixodes siculifer* Megnin, 1880. Female. *Ixodes vespertilionis* C. L. Koch, 1844; *Ixodes flavipes* C. L. Koch, 1844; *Haemalastor gracilipes* Frauenfeld, 1854; *Sarconyssus flavipes* Kolenati, 1857; *S. hispidulus* Kolenati, 1857; *S. brevipes* Kolenati, 1857; *S. kochi* Kolenati, 1857; *S. flavidus* Kolenati, 1857.

FEMALE (fig. 19 *a*)[1]. Body oval. Length 4 to 6 mm. when fasting, to 6 or 8 mm. when replete. Colour when fasting from a light to an earthy yellow. A thick marginal dorsal pad or swelling extends, when fasting, half-way up the shield and terminates at the sides. Body thickly covered with whitish hairs except on the shield, which is light brown, elongated, lance-shaped and wider in the middle. Beneath, the sexual orifice is situated opposite the haunches of the third pair of legs. Rostrum often carried perpendicularly. Hypostome lance-shaped, and very pointed, with a wide base, covered with long, sharp teeth arranged in 4 or 5 rows on each side. Porous spaces well developed. Palpi very similar to those of the female of *I. ricinus*. Legs long.

MALE. Body, flat oval, dark red-brown in colour. Length 4 mm. On the back a narrow marginal pad or swelling, pointed in front, enlarged behind, extending almost to the stigmata. Tegument orna-

[1] The hypostome of the specimen figured is concealed by a piece of bat's flesh adhering to it.

mented with patterns or shields, which vary considerably in different individuals, some being altogether without them, whilst in others they are well developed. Genital orifice situated opposite the spaces between the second and third pair of legs. The grooves underneath resemble those of *I. hexagonus*, but are more parallel. Rostrum generally carried perpendicularly. Palpi club-shaped (fig. 15), wide apart at the base. Legs very thin and long, longer than in the male. The fourth pair the longest.

NYMPH. Oval body, length 1 to 2 mm. Yellowish or reddish in colour. A few short bristles. Rostrum similar to that of larva, but more developed.

LARVA. Body oval. Length 0·2 mm. Yellowish when fasting, blood-red when distended. Rostrum not inflected, otherwise almost resembling that of the female, but the hypostome has only 2 rows of teeth on each side.

The specimens sent me by Mr Newstead consist of two partly distended nymphs and one fasting female, all taken feeding on the Lesser Horseshoe Bat (*Rhinolophus hipposideros*) from a cave at Cefn, North Wales, on April 4th, 1896, but these were not examined until now[1]. This is the first time this species has been reported in this country, though the probability of its occurrence was mentioned by me in my notes to *Science-Gossip* in 1901.

The above descriptions are extracted from those of Neumann.

(C) ANAL GROOVE ENCIRCLING ANUS BEHIND.

(b^1) *APONOMMA* Neumann, 1899.

No eyes. Base of rostrum generally pentagonal; palpi long. Body of male either wider or nearly as wide as long; beneath naked. Dorsal shield covering the whole body, and generally with green metallic marks. The shield of the female shorter and scarcely any longer than wide, ordinarily marked with three green metallic spots in a triangle.

This genus is exotic, and it is almost exclusively parasitical on snakes and saurians. Twelve species are described; but none are British.

(b^2) *AMBLYOMMA* Koch, 1844.

Synonym: *Ixodes* Latreille, 1795.

Eyes usually flat and but little apparent; sometimes brilliant; placed on the outer edge of the shield. Rostrum long. Anal groove

[1] Two other females found at the same place on Dec. 2nd, 1905, by Mr Oldham of Knutsford are deposited at the British Museum.

open in front, joining the sexual grooves. Dorsal shield often marked with coloured designs. No ad-anal shields on the male. Peritremes generally triangular, with rounded angles. Eleven marginal posterior indentations nearly always present, especially in the male.

Professor Neumann describes no less than 86 species of *Amblyomma*, mainly from tropical and sub-tropical climates. One species, *A. hebraeum*, known at the Cape as the "bont" or variegated tick, is the carrier of "heartwater" in sheep, which Mr Lounsbury says "is gradually rendering the splendid veldt of the infected districts useless for sheep farming." Not any British species.

(b^3) *HYALOMMA* Koch, 1844.

Eyes generally round and brilliant (fig. 10), sometimes flat and little noticeable. Rostrum long. Anal groove open in front, joining the sexual groove with another extending from the anus to the posterior margin (fig. 12). Body elongated oval. Colour brown, more or less dark. The male has two pairs of ventral shields, two of which are ad-anal and large, with two others outside, added to which are often two accessory ones, or lamellae, behind the ad-anal shields (fig. 12).

Only three species are described by Professor Neumann, one of which—*H. aegyptium* Linn.—is known at the Cape as the "bont-legged tick," where it attacks small stock and ostriches, as well as cattle and horses, and is considered second only to the "bont tick" as a pest to farmers. It is known probably all over Africa and the greater part of Asia. No less than thirty synonyms are given for this species, showing the great confusion there has been in the nomenclature of ticks. No British indigenous species is known, but one, *H. syriacum*, has been taken on imported tortoises.

Hyalomma syriacum Koch.

Synonym: *Hyalomma affine* Neumann, 1899.

FEMALE. Length, fasting, 6 mm., when distended up to 13 mm.; shield oval, and but little longer than wide, each anterior angle prolonged to nearly half way up the palpi; punctuated sparsely but deeply; eyes small; body reddish-brown. Two very minute dorsal spiracles behind the shield. Coxae of front legs divided with two blunt spines or tubercles; the other haunches with two small tubercles at the outer edge of each. Tarsi short and thick, and suddenly attenuated at the end, which in the three posterior pairs is furnished with a small hook.

MALE. Length, 6 mm.; shield, reddish-brown, bare, anterior angles projecting little; grooves at the neck short and deep, none at the sides; punctuations sparse, equal, and large; underside reddish-brown, sometimes yellow; anus a little behind the orifice of the stigmata; anal shields wide and short; peritremes short and comma-shaped (fig. 12).

Mr Pocock mentions this tick as having been found at Feltham in Surrey, and another was sent me by Mr F. Noad Clarke. The latter was a distended female, which he had exhibited at the South London Entomological Society in June, 1899. Others taken from tortoises imported from abroad have been received by me.

RHIPICEPHALAE.

Synonym: *Conipalpi* Canestrini.

The Rhipicephalae are characterised by their palpi, which are short and more or less conical or subtriangular—not, or but slightly, longer than broad (fig. 27). The upper face of the base of the rostrum is triangular and elongated transversely in *Haemaphysalis* and *Dermacentor*, whereas in *Rhipicephalus* it is hexagonal, and in consequence is provided with salient lateral angles. The underside of the male is unprovided with shields in *Haemaphysalis* and *Dermacentor*, whereas *Rhipicephalus* has two to four symmetrically disposed at the sides of the anus (fig. 29). The absence of ventral shields is almost always compensated for in *Dermacentor* by the great development of the haunches of the fourth pair of legs (fig. 28). *Haemaphysalis* is distinguished, independently of the absence of ventral shields in the male, by the absence of eyes, and by the form of the second joint of the palpi, which in both sexes makes a lateral projection more or less marked (fig. 30).

(c) *HAEMAPHYSALIS* Koch, 1844.

Synonyms: *Rhipistoma* Koch, 1844; *Gonixodes* Dugés, 1888; *Opistodon* Canestrini, 1897.

No eyes; base of rostrum in a rectangle, twice as wide as long. Palpi conical, second joint having a strong conical lateral projection (fig. 30). Peritreme round, or shaped like an abbreviated comma. No shields on ventral face of male. Coxae of first pair of legs not bifid, those of the fourth pair of normal size in the male. Colour uniform brownish.

Of this genus twenty-two species are described from Asia, Africa, Europe, and America, one of which, *H. punctata*, is British.

Haemaphysalis punctata Canestrini and Fanzago, 1877–8.

Synonyms: *Haemaphysalis sulcata* Canestrini and Fanzago, 1877–8; *Rhipicephalus expositicius* Koch, 1877; *Haemaphysalis peregrinus* Cambridge, 1889; *Herpetobia sulcata* Canestrini, 1890.

FEMALE (fig. 31), fasting, 3·44 in length to 12 mm. when replete. Dorsal shield deeply indented in front to encompass the base of the rostrum. Colour reddish-brown, when replete of a leaden grey, which turns to a deep red-brown in alcohol. Rostrum, shield, and legs always brownish. The body above and below punctuated finely and regularly all over. Sexual orifice opposite the coxae of the second pair of legs in both sexes. Shield coarsely and regularly punctate. Peritremes whitish and nearly round. Labium furnished with numerous very small teeth, arranged in five rows on each side. Palpi a little longer than the labium, the first joint short and narrow, the second and third much widened on the dorsal face. Legs comparatively short, coxae with a wide, short, blunt spine; tarsi short and terminated with a spur, which is small on the first pair.

MALE (fig. 32). Length, 3·10 mm. Body rather narrow, reddish-brown or yellowish. Dorsal shield covering nearly the whole body; cervical grooves deep, short and wide in front; numerous punctuations over its whole surface. Eleven indentations on posterior margin of body; peritremes lighter in colour, large, and somewhat comma-shaped. The three anterior pairs of legs with a short spine on the haunches; the fourth with a very long one directed backwards, and being at least as long as the haunch.

NYMPH. Length, 2·50 mm. to 3·00 mm. Body oval, varying from light yellow to dark red-brown. Dorsal shield rounded, with a few punctuations, otherwise like that of the female. Ventral face like the female, but the sexual orifice nearly obsolete. No spur on the tarsi.

LARVA. Body short, oval. Length, 1·20 mm.

This species is somewhat widely distributed, but is not common anywhere. The specimens taken are never very numerous. It is found on sheep, especially behind the ears; on goats, cattle, horses, etc. British specimens were sent to me by Mr Pocock, taken from a hedgehog at Dungeness, consisting of a male and distended female. I have received others taken from sheep in England, but locality not stated.

(d^1) *RHIPICEPHALUS* Koch, 1844.

Synonyms: *Acarus* Linn., 1758; *Ixodes* Latreille, 1795; *Phaulo-ixodes* Berlese, 1889; *Boophilus* Curtice, 1890.

Eyes distinct. Base of rostrum wider than long, hexagonal on the dorsal side, forming a prominent angle at each side. Palpi short, wide (fig. 27). Coxae of the first pair of legs with two spines, usually strong. Peritremes of female in form of a short comma, generally long in the male. The male has one or two pairs of ventral shields; one pair placed on each side of the anus, triangular, sometimes rectangular, large; a second pair, if present, smaller and placed outside.

M. Neumann describes twenty-three species of this genus, most of which are African. It is to some of these that is to be attributed the immense damage to cattle already referred to, which is caused by carrying the microbes of the disease known as "tick fever," "Texas fever," etc., from diseased to healthy animals.

In the Cape Colony *R. decoloratus*, called the "blue tick," and *R. evertsi*, called the "red tick," are best known as such; in the Southern States of North America a closely allied species, *R. annulatus*, is the chief cause of the disease, which in Australia is represented by a slightly different form named *R. australis* by Mr Fuller. No British species is known; but one, *R. sanguineus*, is so widely distributed that there is every possibility of its occurring in England. It is found not only in France and the south of Europe, but in Asia, Africa, America, and Australia.

(d^2) *DERMACENTOR* Koch, 1844.

Synonyms: *Ixodes* Latreille, 1795; *Pseudixodes* Haller, 1882.

Eyes present. Base of rostrum wider than long, rectangular on the dorsal face. Palpi short and thick. Peritremes shaped like a short comma. The ventral side of the male has, like the female, no shields. Haunches of the first pair of legs bidented in both sexes; those of the fourth in the male greatly enlarged (fig. 28). Dorsal shield generally ornamented with various designs.

Seventeen species of this genus are described. One only is British.

Dermacentor reticulatus Fabricius.

Synonyms: *Acarus reticulatus* Fabricius, 1794; *Ixodes reticulatus* Latreille, 1804; *Cynorhaestes pictus* Hermann, 1804; *I. marmoratus*

Risso, 1826; *Ixodes pictus* Gervais, 1844; *Dermacentor reticulatus* Koch, 1844–47; *D. albicollis* Koch, 1844–47; *D. pardalinus* Koch, 1844–47; *D. ferrugineus* Koch, 1844–47; *Ixodes holsatus* Koleuati, 1857; *Pseudixodes holsatus* Haller, 1882; *Haemaphysalis marmorata* Berlese, 1887; *Acarus marginatus* Sulzer; *Crotonus variegatus* Dumeril, 1829.

FEMALE (fig. 33). When fasting, 3·86 mm. long by 2 mm. wide. Body depressed, larger behind. Colour reddish-brown. Shield very large, extending to the level of the third pair of legs, punctuated with a few large and many small punctuations. Colour milky-white, variegated with reddish-brown. Sexual orifice is opposite the coxae of the second pair of legs. Sexual grooves near together in front, rapidly diverging behind the haunches of the fourth pair, and terminating between the second and third festoons on the posterior margin of the body. Peritreme comma-shaped, short, and rounded. Coxae of front legs deeply bifid, the others with a moderate spine. A strong claw at the end of the tarsi of the three posterior pairs of legs, very small in the front pair. Length when replete up to 16 mm. Colour light brown. When depositing eggs, mottled with dark brown above and beneath. Legs brown.

MALE. Very like female (fig. 34). Shield reddish-brown, variegated with milky-white pattern; in front this takes nearly the appearance of the shield of the female, margined by a white border behind. Coxae of the fourth pair of legs three times the size of the third. Palpi having on the second joint a sharp spine pointing backwards (fig. 35), which is less pronounced in the female. Length 4·20 mm.

I am not aware that the nymph or larva have been described.

This species varies very much in individuals, both in shape and colouring. It occurs in England occasionally on sheep. Specimens have been sent to me by Mr Pocock which were found on sheep at Revelstoke in Devonshire. It is widely distributed in Europe and Asia. It also attacks cattle, deer, goats, roe-deer, and even man. Mrs Richardson stated that in March, 1902, this species was so numerous in her garden at Stoke House, Revelstoke, as to be a nuisance to those gathering flowers. It is most probably an imported species that has become acclimatized, in which case, as it is hardy and active, it is likely to become widespread and troublesome.

TABULAR SYNOPSIS.

The following is a short tabular synopsis of the foregoing classification of the Ixodidae:

I. Rostrum concealed beneath the fore-part of the body, except in the immature states; no dorsal or ventral shields,—

ARGASINAE.

(*a*) Body flat with thin edges, finely shagreened and punctuated, narrower in front. No eyes . . . . *Argas*

(*b*) Body with thick sides, often densely covered with small, round, shining granules in various patterns. Eyes sometimes present[1]. *Ornithodoros*

II. Rostrum terminal. Body more or less covered with a dorsal shield. Considerable difference generally between the sexes. Dorsal base of the rostrum of female with two symmetrical hollows finely punctuated, which are absent in males, nymphs, and larvae.

IXODINAE.

(A) Rostrum and palpi longer than broad (fig. 11).

(*a*) Anal groove contouring anus in front (fig. 11). No eyes.

(a^1) Palpi caniculated in both sexes . . . . *Ixodes*

(a^2) Palpi claviform, not caniculated in the male. Anal groove absent in the female . . . . *Ceratixodes*

(a^3) Palpi claviform, not caniculated in the male (fig. 15). Legs very long. Anal groove present in both sexes . . . . *Eschatocephalus*

(*b*) Anal groove contouring anus behind (fig. 12).

(b^1) No eyes. Ad-anal shields . . . . *Aponomma*

(b^2) Eyes present (fig. 10). Males have no ad-anal shields. *Amblyomma*

(b^3) Eyes present. Males have ad-anal shields (fig. 12) . *Hyalomma*

(B) Labium and palpi short and more or less conical; not, or very little, longer than broad.

RHIPICEPHALAE.

(*c*) No eyes nor ventral shields in the male. Rostrum rectangular; second joint of palpi with lateral projection (fig. 31) . . *Haemaphysalis*

(*d*) Eyes present.

(d^1) Rostrum with salient angles. Either two or four shields at the side of the anus of the male (fig. 29) . . . . *Rhipicephalus*

(d^2) Rostrum rectangular. No ad-anal shields, but usually a great development of the coxae of the fourth pair of legs in the male (fig. 30) . . . . *Dermacentor*

[1] This is denied by Dr Marx in *Proceedings of Entomological Soc.*, Washington, Vol. II., No. 2, 1892.

APPENDIX.

PAIRING OF SEXES.

THERE are considerable doubts as to the method of sexual intercourse in the different genera of the *Ixodidae*. Dr Marx writes "that the orifice of the oviduct in the matured female and that of the sexual organs of the male are situated very close to the insertion of the capitulum[1]."

Dr Cooper Curtice writing of the cattle tick (*Rhipicephalus annulatus*) says, "The external genitals which appear in the adults are very similar in each sex, and occur between the bases of the second pair of legs[2]"; and again, "The male places himself in copulation, belly to belly with the female, attaches to the host by his beak, and winds his legs around those of the female, thus bringing their external genitals in contact[3]."

Others have held the same view, and as recently as last November Dr Todd referring to *Ornithodoros moubata* (?) says, "In coitus the male lays hold of the posterior margin of the female, and turning on his back, crawls forward beneath the female, until the genital pores are in opposition. Pairs are often formed and remain for hours *in coitu*[4]." One writer goes so far as to assert that the tail-like projection in *Rhipicephalus annulatus* is a penis!

It is certain, notwithstanding, that in the case of several of the species of *Ixodidae*, insertion of the mouth organs of the male into the orifice of the female takes place at the time of sexual intercourse. In proof of this I have found spermatozoa in the females of *I. ricinus* immediately after pairing effected in this manner (fig. 36)[5]. A similar manner of pairing has been observed by me in the case of *I. hexagonus*, and with *Ceratixodes putus*, which last observation has been confirmed by Mr Hewett of York. This method of intercourse seems to have been noticed by earlier observers. C. L. Koch in his *Uebersicht der Arachnidensystems*, part IV. page 10 (1847), says, literally translated, "I have

[1] *Proceedings of Ent. Soc.*, Washington, Vol. II., No. 3, p. 273, 1892.

[2] "About Cattle-ticks," by Cooper Curtice, M.D., *Journal of Comparative Medicine*, Jan., 1892.

[3] *Agricultural Gazette*, N. S. Wales, July, 1896.

[4] *The Nature of Human Tick Fever in the Congo Free State*, Nov., 1905. Liverpool School of Tropical Medicine, Memoir XVII.

[5] In this illustration two males are shown, one *in coitu*, the other waiting.

already in the preliminary treatise of which I have made mention alluded to the fact that, according to the observations of the celebrated naturalist De Geer, large ticks have been found that have a small tick attached to their ventral surface with its proboscis sunk into an aperture in the body of the larger. This condition, in which ticks are frequently found, is nothing but coition." Unfortunately no particular species of ticks are mentioned. Mr Lounsbury of the Department of Agriculture, Cape Colony, confirms these observations with regard to *Ixodes pilosus*, *Amblyomma hebraeum*, known in Cape Colony as the "bont tick," *Rhipicephalus evertsi*, the "red tick," *R. decoloratus*, the "blue tick," *Ornithodoros savignyi*, and *Argas persicus*. He also kindly sent me in 1902 spermatozoa taken from the females, after copulation, of *R. evertsi*, *R. decoloratus*, and *A. hebraeum*.

Since these have been noted in such widely different species and by such a careful observer, it seems more than probable that the habit is universal amongst the *Ixodidae*.

Mr R. T. Lewis[1] drew attention to two organs at the base of the hypostome, which if examined immediately after forcibly separating the male from the female, "presented the appearance of flexible semi-transparent tubular papillæ, which conveyed the impression to my mind that here possibly were the organs by means of which actual impregnation took place."

Dr Nuttall, however, to whom I am indebted for most valuable assistance, is of opinion that the insertion of the rostrum by the male is merely for the purpose of holding on to the female, and that the external male sexual organ is not obsolete. He considers that the spermatophores must be remitted therefrom and be in some way passed forward to the vulva, possibly by a mechanism analogous to the ovipositor of the female.

Ticks of different species vary in their habits when pairing. The males of *I. ricinus* are only to be found *in coitu* with distended females on the host. At the same time virgin males and females may be collected separately, but never in intercourse, from rushes or coarse herbage.

Immediately on being confined together in a bottle which is warmed in the pocket, pairing takes place, and usually continues for some hours. I found that if prematurely separated no sperms had passed from the male to the female.

[1] *Quekett Microscopical Society Journal*, October, 1900.

The male of *R. decoloratus* also seeks the female and remains *in coitu* several days[1]. (Lounsbury.)

The habits of *A. hebraeum* are quite different. The male first establishes himself on the host, and after he has been affixed several days he becomes a source of attraction to the females. These latter will surround him and fight amongst themselves to secure him. A male remained attached to a host almost a full year. (Lounsbury.)

SPERMATOZOA.

The spermatozoa of *Ixodes ricinus* are shaped as shown in Fig. 37. I have failed to observe any movement in them. They are usually, but not always, accompanied by a very fine worm-like body about half the length of the spermatozoon. This takes a darker stain with haematoxylin than the larger body, from which it becomes easily separated by pressure. This darker body Dr Nuttall considers to be undoubtedly nuclear. Mr Lounsbury writing in 1902 said, "The sperms vary in shape in the different species. There is no doubt about their being sperms. They do not occur in the males of *hebraeum* or *decoloratus* until these have been feeding some days and are ready for females. Of this I am positive from the examination of much material. The prettiest feature is finding them in the females. By carefully removing the whole dorsal skin, and washing out the contents of the digestive tract of fully engorged females, the forming ovaries are easily placed, and between them in the shape of a rotund, dense, white body is the receptaculum containing the sperms. It has a tube leading to the oviduct. When this is cut the sac may be removed entire and burst under the microscope when the myriads of sperms fly out. The sac is quite visible to the naked eye. I have seen several in *decoloratus* and *hebraeum*. Of course there is only one sac in a female. By carefully opening *hebraeum* males, I have found what I take to be the testes. At least I can get out a pair of bodies which swarm with sperms."

HEADLESS FEMALE.

The remarkable vitality of the headless female of *Ixodes ricinus*, referred to on page 401, is worthy of further notice. A reproduction of a photograph of the creature (fig. 38) is given for comparison with that of an ordinary female of the same species, shown by fig. 11, with the

[1] *Cape Agricultural Journal*, Nov. 24, 1898.

mouth organs complete. That such a deformed individual could survive at all seems wonderful. It will be seen that beyond a slight prominence, no vestige of any capitulum or mouth organs was present. This individual proved beyond all question the power of a tick to live many months without food of any sort.

Argas persicus Fischer de Waldheim, 1823.

As this species has often been mistaken for *Argas reflexus*, a figure (39) of the male is here given for comparison with that of the male of *reflexus* (fig. 7). The chief and characteristic differences are the wrinkled margin of *A. reflexus* as compared with the discs on that of *A. persicus*, and the prominent knobs on the tarsi of the former species, shown clearly in fig. 6 of the female. These differences are similar in both sexes.

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Fig. 1.
Female ticks ovipositing.

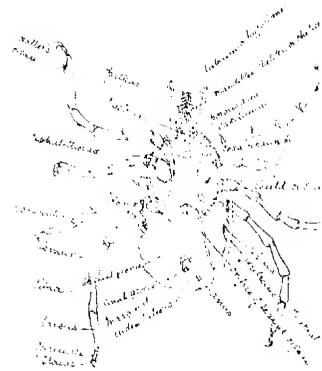

Fig. 2.
Diagram.

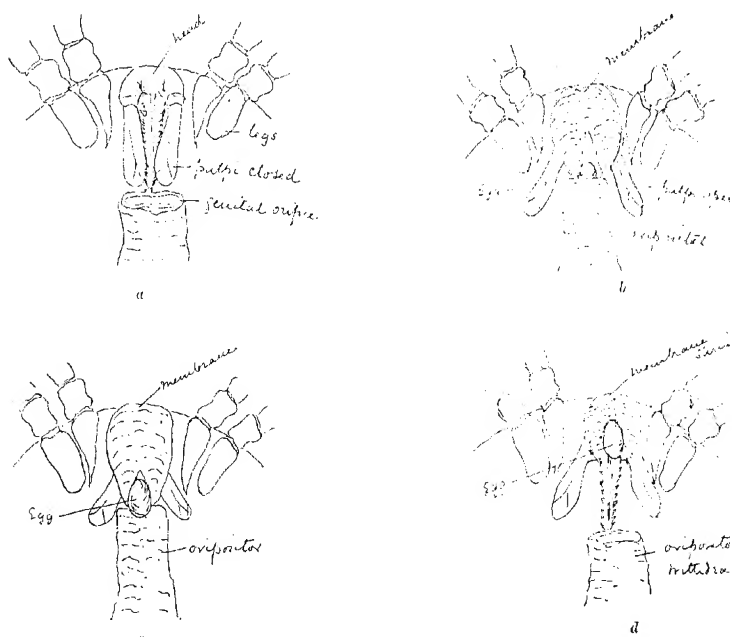

Fig. 3.
Method of oviposition.

Fig. 4.
Ixodes ricinus, ♀. ×6.
Fully distended and about to lay eggs.

Fig. 5.
Ixodes ricinus, ♀. ×2.
Ovipositing.

Fig. 6.
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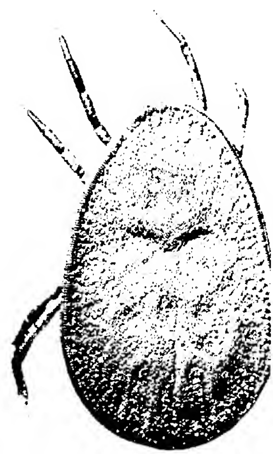

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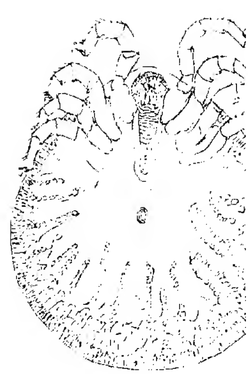

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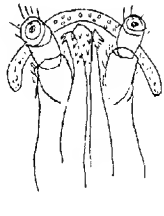

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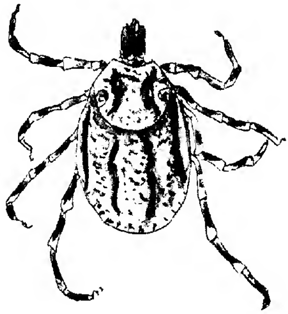
...ilionis. Rostrum enlarged.



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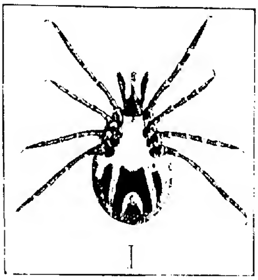

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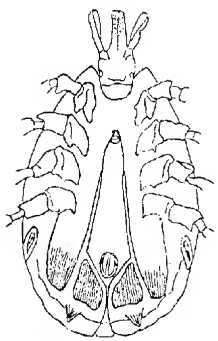
Ixodes ricinus, ♂. × 9.



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Hyalomma, shewing anal groove and plates.

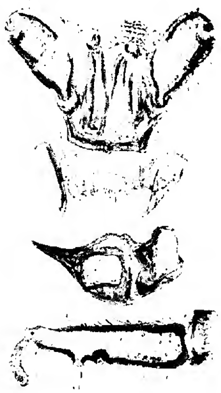

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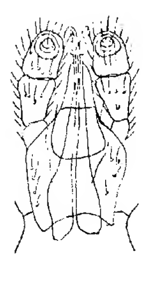
Fig. 14.
Ixodes ricinus, ♀. Coxa, caruncle and tarsus of fore-leg.



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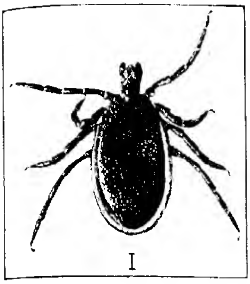
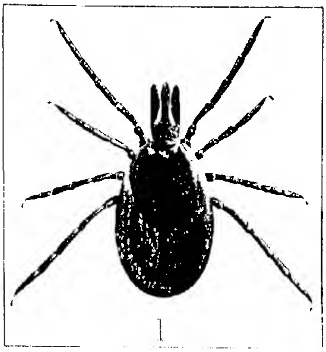


Fig. 16.
Ixodes ricinus, ♂. ×12.



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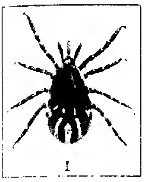

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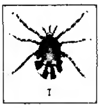

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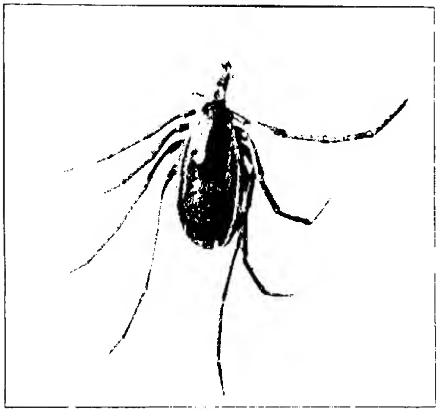

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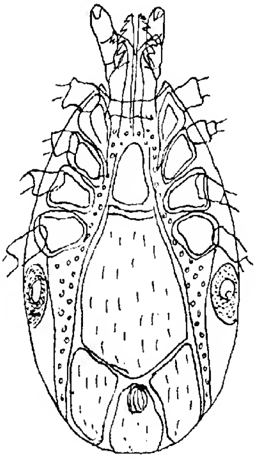

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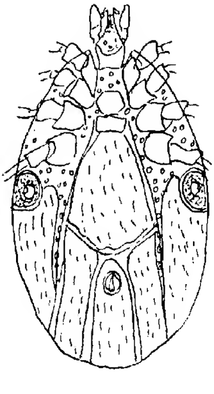

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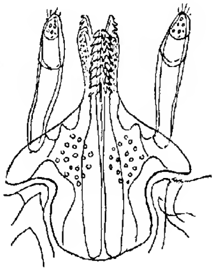

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Ixodes tenuirostris, ♀.

Fig. 24.
Ixodes tenuirostris, ♂, ×24.

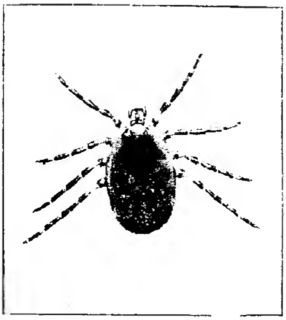

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Fig. 26.
Ceratixodes putus, ♂. ×7.

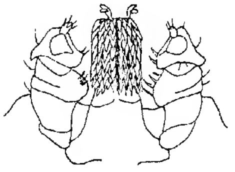

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Fig. 28.
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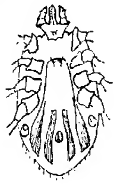

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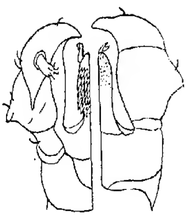

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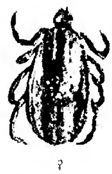
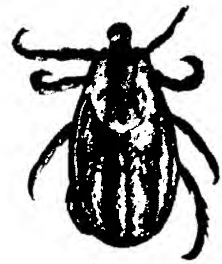


Fig. 31. Fig. 32.
Haemaphysalis punctata. ×7.



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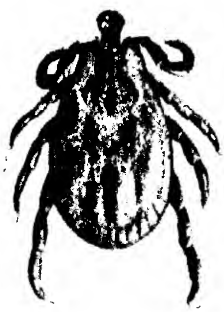

Fig. 34.
Dermacentor reticulatus, ♂. ×10.

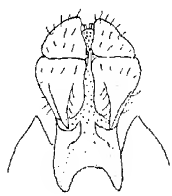

Fig. 35.
Dermacentor reticulatus,
palpi of male.

Fig. 36.
Ixodes ricinus. ×3.
in coitu.

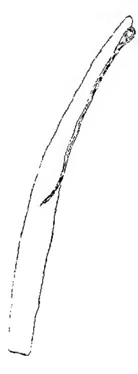

Fig. 37.
Spermatozoon of
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Fig. 38.
Ixodes ricinus, headless female. ×6.

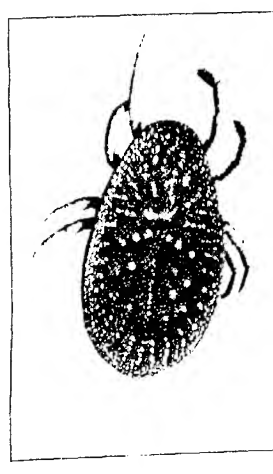

Fig. 39.
Argas persicus ♂ ×9.

CITRATE SOLUBILITY OF PHOSPHORIC ACID IN FERTILIZERS.

By JOHN K. S. DIXON,

Chemist with Henry Richardson and Company, York.

FROM time to time treatment with solutions of ammonium citrate and citric acid of various strengths has been advocated for the determination of the available phosphoric acid in manures, but up to the present time has been applied to mineral manures almost exclusively. The action of these solvents on fertilizers containing organic matter has been so little enquired into that the writer has been led, on the suggestion of Messrs Henry Richardson & Co., to undertake the investigations which form the basis of the present communication.

The effect of ammonium citrate on bones and various other fertilizers has been investigated in America by Huston and his colleagues who found that the normal tricalcium phosphate as it exists in bones and similar preparations is dissolved by ammonium citrate solution[1]. Their results, however, are not of great value, since the treatment with citrate solution was in most cases limited to half-an-hour and in no case exceeded 10 hours.

Wagner and Maercker compared the solubilities of bone-meal and basic slag in citric acid solutions, and found that half-an-hour's treatment extracts more phosphoric acid from slag than from bones, but when the time of action is prolonged to more than five days the greater proportion is obtained from bone-meal[2].

Methner remarks that it is strange that the superiority of the phosphoric acid in bone-meal over that in basic slag for manuring purposes is not indicated by analytical results, for on using Wagner's method, the percentage of the total P_2O_5 dissolved was less in the case

[1] Wiley. "Report on Fertilizers to Indiana State Board of Agriculture, 1882." *Proceedings of the Association of Official Agricultural Chemists.* Atalanta, 1884, &c.

[2] Hoffmeister. *Landw. Versuchs. Stat.*, 1898, 50, 363.

of bone-meal than in the case of basic slag[1]. This he finds to be due to the fact that the citric acid must be in a definite ratio to the phosphoric acid, which in the case of a slag with 16 per cent. P_2O_5 was 100 : 8. This ratio must also be maintained in treating the bone-meal which contains 30 per cent. P_2O_5. By using 2·5 grammes of bone-meal instead of 5 grammes and following the same method Methner claims that satisfactory results were obtained.

L. Gebek investigated the solubility of the phosphoric acid of bone-meal in Wagner's citric acid solution, and found that this quantity depended in some measure on the fineness of grinding. He also showed that the phosphates of bone-meal are soluble to a much less extent after ignition and also after the gelatin has been extracted from the substance by steaming, than they were in the original material[2]. Gebek concludes that only a small portion of the phosphoric acid of bone exists as tricalcium phosphate, and he suggests that the bulk exists as dicalcium phosphate, the remainder being in the form of an organic tribasic phosphate. On ignition the organic base would be destroyed, and lime would fill its place, forming tricalcium phosphate, thus reducing the solubility in citric acid.

For the purpose of the present investigations a series of manures was selected representative of the more common fertilizers which are added to the soil with the object of supplying phosphoric acid in a form slowly attacked by the soil water. In every case the sample used for the analyses may be regarded as thoroughly representative of each material as supplied in bulk to farmers.

The solvent effect on each sample of the following six solutions has been compared:

(*a*) *Alkaline ammonium citrate*[3] as recommended by Petermann in his revised method of estimating citrate-soluble phosphoric acid in superphosphates. The solution is prepared by adding 50 c.c. ammonia of 0·92 specific gravity to a litre of neutral ammonium citrate of 1·09 specific gravity.

(*b*) *Neutral ammonium citrate*[4] of 1·09 specific gravity as formerly recommended by Petermann.

(*c*) *Acid ammonium citrate*[5] as recommended by Wagner for

[1] Methner. *Zeits. angew. Chem.*, 1901 [6], 134–135.

[2] L. Gebek. *Zeits. angew. Chem.*, 1894, 193–197.

[3] Publication of the *Station agronomique de l'État de Gembloux*. *Landw. Versuchs. Stat.* **50**, 171. (1897).

[4] *Ibid.*

[5] *Chem. Zeit.*, 1886, 19, 37, and 1887, 905.

superphosphates: viz. a solution containing 3 per cent. citric acid as neutral ammonium citrate and 0·2 per cent. as free acid.

(*d*) 2 *per cent. citric acid*[1] as recommended by Wagner for basic slag.

(*e*) 1 *per cent. citric acid*[2] as recommended by Dyer in analysis of soils.

(*f*) 0·1 *per cent. citric acid*[3] as recommended by Hughes.

In the cases of solutions (*a*) and (*b*) the treatment was in accordance with the directions of Petermann, viz., in method (*a*) the mixture is allowed to stand for 15 hours at the ordinary temperature and then for one hour at 40° C., whilst in method (*b*) the preliminary 15 hours' standing is omitted.

In all other cases the mixture was allowed to stand 18 hours at the ordinary temperature with violent agitation at intervals, this treatment corresponding, in the experience of the writer, with the half-hour's shaking commonly recommended.

In all the analyses the proportion of fertilizer to solvent was the same, viz., 100 c.c. of solvent per 1 gr. of fertilizer.

The substance was weighed into a mortar, triturated with the solvent and transferred to a measuring flask in which the digestion was carried out.

The percentage of phosphoric acid in the citrate extract after filtration was estimated by the citrate method. It is well known that this method is not wholly satisfactory in the ordinary course for solutions containing a low percentage of P_2O_5, or in presence of much organic matter. This difficulty may be overcome, however, as demonstrated by Wiley, and amply verified by the writer, by adding to the solution previous to precipitation with magnesia mixture a definite volume of phosphatic solution of known strength, a corresponding deduction from the weight of magnesium pyrophosphate obtained being made[4]. This procedure was adopted with the samples containing less than 15 per cent. P_2O_5.

The citrate and magnesia mixture were added simultaneously in

[1] Wagner. *Landw. Versuchs. Stat.*, 1895.

[2] *Journ. Chem. Soc.*, March, 1894.

[3] *Journ. Soc. Chem. Ind.* xx., p. 325 (April, 1901). According to Hughes' method, the proportion of manure to solvent is made 1 : 1000, and the time of digestion 24 hours. In the present investigations the above proportion was made 1 : 100, and the time 18 hours in order to obtain uniformity between this and the other two citric acid methods.

[4] Runyan and Wiley. Paper presented to the Washington Section of the American Chemical Society, 1895.

order to avoid the precipitation of silica; for Wagner showed that citrate extracts (particularly after long standing) have a tendency to separate silica when the alkaline citrate is added before the magnesia mixture, and that this does not occur when added together[1]. The citrate-magnesia mixture is prepared by dissolving citric acid (200 grammes) in 20 per cent. ammonia and diluting to one litre with the same ammonia. The solution is then mixed with an equal bulk of magnesia mixture.

In the tables the results are given in two columns, (1) the absolute percentage of citrate soluble P_2O_5 in the sample, (2) the percentage of the total P_2O_5 which has been dissolved—*i.e.* $\frac{\text{citrate soluble } P_2O_5}{\text{total } P_2O_5} \times 100$, the latter often being referred to as the 'solubility.'

The data are so conflicting at the present stage of investigation that it is impossible to do more than draw attention to apparent anomalies and points of interest in general and where possible to suggest explanations.

The solvents may be classified as

(*a*) solutions of ammonium citrate, *alkaline, neutral* and *acid*,

(*b*) " " citric acid, *2 per cent., 1 per cent.*, and *0·1 per cent.*

These two classes are not strictly comparable, and it is therefore convenient to discuss them separately.

The products investigated also differ considerably in nature but may be grouped as Steamed Bones, Raw Bones, Fish Meals, and Guanos, and they will therefore be dealt with in separate paragraphs under these heads.

STEAMED BONES.

The physical properties of all the five samples were practically identical, the difference in fineness of grinding between the 'meals' and 'flours' being scarcely perceptible.

(*a*) *The action of ammonium citrate solutions.*

The highest percentage of phosphoric acid is dissolved by the neutral, the next highest by the acid, and the lowest by the alkaline ammonium citrate solution.

It is noteworthy that the total phosphoric acid content is practically the same in each sample, and therefore, other conditions being equal,

[1] P. Wagner. *Chem. Zeit.*, 1897, 21, 905.

the solubilities in one and the same solvent might be expected also to be nearly equal, if anything the least quantity being dissolved in the case of No. 4 (with the lowest content of P_2O_5), and the greatest in that of No. 5 (with the highest P_2O_5 content). However, the reverse holds good in every case when the solubilities are compared, so that either the phenomenon is not one of simple solution, or there must be a fundamental difference in the phosphates of the bones. In the latter

TABLE I.

No.		Nitrogen %	Total P_2O_5 %	Solubility in					
				Alkaline Ammonium Citrate		Neutral Ammonium Citrate		Acid Ammonium Citrate	
				Absolute P_2O_5 %	Per cent. of Citrate soluble in Total	Absolute P_2O_5 %	Per cent. of Citrate soluble in Total	Absolute P_2O_5 %	Per cent. of Citrate soluble in Total
1	Steamed Bone Meal...	0·93	29·02	4·36	15·02	13·19	45·45	5·17	17·81
2	,, ,, ,, ...	1·86	29·07	2·54	8·73	9·09	31·27	8·92	30·68
3	Steamed Bone Flour.	1·12	28·60	4·64	16·22	11·90	41·60	8·00	27·97
4	,, ,, ,, ...	1·34	28·27	4·94	17·47	11·96	42·30	10·97	38·80
5	,, ,, ,, ...	1·07	29·14	4·58	15·71	12·22	41·93	4·99	17·12

alternative we might expect to find characteristic differences in the solubilities in the different solutions. Such is indeed the case to a remarkable degree. Thus while Nos. 1, 3, 4 and 5 have similar solubilities in alkaline and neutral solutions, Nos. 1 and 5 are far less soluble in acid citrate than Nos. 3 and 4.

Again, No. 2, Steamed Bone Meal is quite exceptional in its low solubility in alkaline and neutral citrate, whereas in acid citrate its solubility is comparable with that of No. 3 or No. 4 and decidedly greater than those of Nos. 1 and 5.

(*b*) *The action of citric acid solutions.*

It is to be noted that with the 2 per cent. solution the solubilities are in order identical with the order of the percentages of the total phosphoric acid, when the trifling difference of 0·05 per cent. P_2O_5 in the total contents of Nos. 1 and 2 is overlooked. This order is not so

noticeable in the case of the 1 per cent. solution, and still less so with the 0·1 per cent. acid.

The results here, as with citrate solutions, point to the operation of some disturbing factor, such as the presence of phosphates of different solubilities in citric acid.

TABLE II.

No.		Nitrogen %	Total P_2O_5 %	Solubility in 0·1 % Citric Acid: Absolute P_2O_5 %	0·1 % Citric Acid: Per cent. of Citric soluble in Total	1 % Citric Acid: Absolute P_2O_5 %	1 % Citric Acid: Per cent. of Citric soluble in Total	·2 % Citric Acid: Absolute P_2O_5 %	·2 % Citric Acid: Per cent. of Citric soluble in Total
1	Steamed Bone Meal...	0·93	29·02	2·60	8·95	13·60	46·84	18·87	65·02
2	" " " ...	1·86	29·07	2·75	9·46	12·76	43·89	18·69	64·29
3	Steamed Bone Flour.	1·12	28·60	2·89	10·10	13·73	48·00	18·33	64·09
4	" " " ...	1·34	28·27	2·50	8·84	12·58	44·49	16·21	57·34
5	" " " ...	1·07	29·14	2·62	9·00	16·16	55·45	20·56	70·55

The data with each separate solution are however far more uniform, the peculiar behaviour of Nos. 1, 2, and 5 towards citrate solutions not being apparent with free acid.

RAW BONES.

This category is intended to furnish examples of bone which retain their full complement of nitrogen, even though the material may have undergone some preliminary treatment. Sample No. 6 represents town-collected bones and No. 7 English raw bone, both of which still contain the natural fat. 'Degreased' bones are represented by Nos. 8 and 9, the fat being extracted on the large scale by benzene.

The three samples of bone sawings are typical pure bone meals, as also the turnings which are a by-product in the manufacture of bone buttons.

The first five were all of a similar fineness of grinding and are such as agricultural merchants sell as 'fine grist.' The sawings were much finer and comparable with steamed bone meal in this respect. The turnings were in thin flakes and exceedingly light.

(a) The action of ammonium citrate solutions.

TABLE III.

No.		Nitrogen %	Total P_2O_5 %	Solubility in Alkaline Ammonium Citrate: Absolute P_2O_5 %	Alkaline Ammonium Citrate: Per cent. of Citrate soluble in Total	Neutral Ammonium Citrate: Absolute P_2O_5 %	Neutral Ammonium Citrate: Per cent. of Citrate soluble in Total	Acid Ammonium Citrate: Absolute P_2O_5 %	Acid Ammonium Citrate: Per cent. of Citrate soluble in Total
6	English Bone Meal*...	4·45	20·14	2·10	10·42	3·35	16·63	3·27	16·23
7	,, ,, ,, *...	5·01	22·00	2·28	10·36	4·19	19·04	4·44	20·19
8	,, ,, ,, †...	4·94	22·81	2·41	10·56	3·94	17·27	3·43	15·03
9	,, ,, ,, †...	5·17	22·46	2·46	10·95	4·21	18·74	5·45	24·26
10	Indian Bone Meal‡ ...	3·35	23·19	1·47	6·33	3·89	16·77	3·44	14·83
11	Bone Sawings‡.........	4·03	25·51	3·25	12·74	9·66	37·87	6·76	26·49
12	,, ,, ‡.........	4·02	24·92	2·57	10·31	10·59	42·49	5·40	21·67
13	,, ,, ‡.........	3·96	25·02	3·58	14·31	9·51	38·01	6·65	26·57
14	Bone Turnings‡	4·07	25·79	4·07	15·77	11·62	45·05	9·15	35·47
15	,, ,, ‡	3·97	25·64	4·58	17·86	12·25	47·77	12·19	47·54

* 'Undegreased.' † 'Degreased.' ‡ Well-cleaned.

In general the solubility is greatest in the case of neutral ammonium citrate. There are two exceptions, viz. No. 7 and No. 9, which both give the highest figure with the acid solution. It may be noted that these two samples, Nos. 7 and 9, are the richest in nitrogen, which may have something to do with their relatively low solubility in neutral citrate, although no connexion between the amount of nitrogenous matter and of soluble phosphoric acid is apparent in the case of the other samples.

As in the case of steamed bones, considerable differences are shown here between products of similar physical characteristics and chemical composition. The results obtained from the bone-sawings are worthy of attention in this connexion. In appearance and fineness they are exactly alike, and although the total phosphoric acid is practically equal in each, yet No. 12 is decidedly less soluble in alkaline and in acid citrate, but more soluble in neutral solvent than the other two (Nos. 11 and 13).

On comparing the two samples of 'degreased' bones it will be noticed that the solubilities do not agree well. Although No. 9 contains less total phosphoric acid than No. 8 yet it has rather higher citrate solubilities, notably in acid solution.

The data for the 'undegreased' meals offer no particular interest.

(*b*) *The action of citric acid solutions.*

TABLE IV.

No.		Nitrogen %	Total P_2O_5 %	Solubility in 0·1 % Citric Acid: Absolute P_2O_5 %	Solubility in 0·1 % Citric Acid: Per cent. of Citric soluble in Total	Solubility in 1 % Citric Acid: Absolute P_2O_5 %	Solubility in 1 % Citric Acid: Per cent. of Citric soluble in Total	Solubility in 2 % Citric Acid: Absolute P_2O_5 %	Solubility in 2 % Citric Acid: Per cent. of Citric soluble in Total
6	English Bone Meal*	4·45	20·14	1·19	5·90	5·60	27·80	9·51	47·23
7	" " " *	5·01	22·00	2·09	9·50	7·55	34·31	11·50	52·27
8	" " " †	4·94	22·81	1·93	8·46	7·65	33·53	11·36	49·80
9	" " " †	5·17	22·46	1·58	7·03	8·60	38·29	12·73	56·67
10	Indian Bone Meal‡	3·35	23·19	1·32	5·69	7·02	30·27	12·22	52·29
11	Bone Sawings‡	4·03	25·51	2·65	10·39	11·94	46·80	18·32	71·81
12	" " ‡	4·02	24·92	2·62	10·51	12·33	49·48	20·16	80·89
13	" " ‡	3·96	25·02	2·68	10·71	12·38	49·48	20·27	81·01
14	Bone Turnings‡	4·07	25·79	2·57	9·96	16·45	63·75	24·41	94·64
15	" " ‡	3·97	25·64	2·49	9·71	15·99	62·36	21·40	83·46

* 'Undegreased.' † 'Degreased.' ‡ Well cleaned.

With the 'undegreased' meals and bone turnings it is seen that the order of solubility in 2 per cent. acid corresponds to the order of the total P_2O_5 in the samples. This does not hold however for the 'degreased' bones, nor for the sawings—No. 11 being notably exceptional. The regularity is still less apparent in the results obtained with the weaker acid solutions.

The exceedingly high solubility of bone 'turnings' No. 14 in the 2 per cent. solution is worthy of note; also the same sample with all three free acid solutions gives higher solubilities than its fellow No. 15, whilst with citrate solutions (Table III.) the order is reversed in the case of each solvent, the difference being most pronounced in acid citrate.

Attention should also be called to the decidedly higher solubilities in 2 per cent. acid of the 'sawings' than of the steamed products (see Table II), which are certainly not more coarse grained than the former.

Fish Meals.

The samples under investigation are representative of several processes of manufacture, yet in general physical properties are closely allied. In the matter of fineness of division No. 19 was the coarsest and No. 20 the finest material, the remaining three samples being intermediate.. As the question of the amount of oil sometimes arises in the consideration of fish meal as a manure, the percentages of this constituent are added to the table. The meals containing a low percentage of oil are manufactured largely from the heads, etc. of 'white' fish, notably cod. A preponderance of herring refuse produces an article inconveniently rich in oil; No. 20 is a typical example of such material.

(*a*) *The action of ammonium citrate solutions.*

TABLE V.

No.		Nitrogen %	Total P_2O_5 %	Solubility in: Alkaline Ammonium Citrate		Neutral Ammonium Citrate		Acid Ammonium Citrate		Oil %
				Absolute P_2O_5 %	Per cent. of Citrate soluble in Total	Absolute P_2O_5 %	Per cent. of Citrate soluble in Total	Absolute P_2O_5 %	Per cent. of Citrate soluble in Total	
16	Fish Meal...	8·97	8·87	1·99	22·43	4·91	55·35	3·62	40·81	4·96
17	" " ...	8·68	10·14	2·51	24·75	6·95	68·54	3·85	37·96	8·48
18	" " ...	8·27	8·88	2·43	27·36	5·69	64·07	4·48	50·45	8·11
19	" " ...	8·30	7·36	1·48	20·11	3·49	47·41	2·94	39·94	8·83
20	" " ...	8·78	6·59	1·71	25·95	3·59	54·47	3·14	47·64	16·46

The order of the solvent power of the solutions remains the same, viz., neutral the greatest, followed by acid, and alkaline citrate in turn; this statement is valid in each case in point.

There is no apparent connexion between the order of the citrate solubility and the order of the percentage of total P_2O_5 or of nitrogen, as was noted in some instances with bones. However, it is noteworthy that

whilst Nos. 16 and 18 have practically the same content of total phosphoric acid, No. 16 the richer in nitrogen (8·97 per cent.) yields lower solubilities than No. 18 (nitrogen = 8·27 per cent) in every case. It will be remembered that the raw bones No. 7 and No. 9 in Table III gave exceptionally low solubilities with neutral solution, at the same time being richest in nitrogenous matter.

It is commonly said that a high percentage of oil in fish meal prevents rapid action of the manure in the soil[1]. This is in nowise borne out by the present results as far as the solubility of the phosphates is concerned; indeed if No. 16 and No. 18 are once more compared, No. 18 containing by far the larger percentage of oil, yields the greater proportion of its phosphates to all three citrate solutions. Again, No. 20 with more than 16 per cent. oil gives solubilities quite comparable with those of the remaining samples.

(*b*) *The action of citric acid solutions.*

TABLE VI.

No.		Nitrogen %	Total P_2O_5 %	Solubility in: 0·1 % Citric Acid, Absolute P_2O_5 %	0·1 % Citric Acid, Per cent. of Citric soluble in Total	1 % Citric Acid, Absolute P_2O_5 %	1 % Citric Acid, Per cent. of Citric soluble in Total	2 % Citric Acid, Absolute P_2O_5 %	2 % Citric Acid, Per cent. of Citric soluble in Total	Oil %
16	Fish Meal...	8·97	8·87	2·14	24·13	5·48	61·78	7·17	80·83	4·96
17	" " ...	8·68	10·14	2·61	25·74	6·05	59·66	8·43	83·13	8·48
18	" " ...	8·27	8·88	2·06	23·20	5·58	62·83	6·96	78·38	8·11
19	" " ...	8·30	7·36	1·50	20·38	4·19	56·92	5·35	72·69	—
20	" " ...	8·78	6·59	1·79	27·16	4·20	63·73	4·26	64·64	16·46

With 2 per cent. solution there is a tendency for the order of the solubilities to arrange themselves in the order of the total phosphoric acid percentages. This was the case with steamed bones (Table II), also with 'undegreased' bones (Table IV). There is no sign of such regularity in the case of the weaker solutions.

[1] "Indeed, some experiments seem to show that an excessive percentage of oil retards decomposition, not only in the fish meal itself, but in the adjacent particles of soil." – *Artificial Fertilizers* (H. Richardson & Co.), 1895.

As regards the influence of the presence of oil, if No. 16 and No. 18 are again compared, it is seen that with 2 per cent. and 0·1 per cent. solutions No. 18 (8·11 per cent. oil) gives the lower solubilities, whilst in the case of the 1 per cent. solution No. 16 (4·96 per cent.) is the less soluble, though in every case there is no great difference. It will also be noticed that the difference of the solubilities in 2 per cent. and 1 per cent. solutions of No. 20 is very small.

Guano.

A study of the analyses of a few cargoes of guano of different origin would at once reveal what a variable material is being dealt with.

Two varieties of guano are now imported:—

(1) Nitrogenous and phosphatic, containing from 7 per cent. to 11 per cent. nitrogen, and 5 per cent. to 15 per cent. phosphoric acid, and generally termed 'ammoniacal.'

(2) Phosphatic, containing upwards of 15 per cent. phosphoric acid with generally less than 3·5 per cent. of nitrogen.

It is almost impossible to say how the various acids and bases in this substance are distributed, as the chemical nature is so highly complex[1].

The samples of phosphatic guano represent two classes, (1) 'older' and (2) 'newer' guano. The former variety has remained for a long period before being worked, and in consequence has lost nitrogen and become more highly phosphatic; this class is represented by samples Nos. 21, 22, and 23. The 'newer' guano is typified by samples Nos. 24 and 25 and their bulks are not of such ancient origin.

(a) *The action of ammonium citrate solutions.*

Generally the phosphates of the samples richest in nitrogen are the more easily attacked in the case of each solvent. The notable exception is No. 27; in the alkaline solution it yields only 19·11 per cent. of its phosphoric acid, an amount comparable with that yielded by the phosphatic sample No. 25 (19·05 per cent.), and less than the solubility of No. 24 (23·41 per cent.).

[1] For detailed analyses of Peruvian guano see Wagner's *Chemical Technology*, 1892, p. 424; or *Manual of Agricultural Chemistry*, Herbert Ingle, 1902, pp. 130–131.

In the case of the phosphatic selection the order of the solubilities in neutral solvent is the exact opposite of the order of the figures for total P_2O_5, and with the acid citrate the absolute percentages show the same characteristic, while with alkaline solution there is no such correspondence.

TABLE VII.

No.	Guano	Nitrogen %	Total P_2O_5 %	Solubility in: Alkaline Ammonium Citrate: Absolute P_2O_5 %	Alkaline Ammonium Citrate: Per cent. of Citrate soluble in Total	Neutral Ammonium Citrate: Absolute P_2O_5 %	Neutral Ammonium Citrate: Per cent. of Citrate soluble in Total	Acid Ammonium Citrate: Absolute P_2O_5 %	Acid Ammonium Citrate: Per cent. of Citrate soluble in Total
21	Peruvian 'Phosphatic'...	2·11	30·45	2·33	7·65	6·95	22·82	5·28	17·34
22	,, ,, ...	1·64	26·13	2·97	11·36	8·38	32·07	6·84	26·17
23	,, ,, ...	1·40	27·28	2·23	8·17	8·28	30·31	6·26	22·94
24	,, ,, ...	2·83	22·64	5·30	23·41	11·20	49·47	10·14	44·78
25	,, ,, ...	3·26	21·36	4·07	19·05	12·57	58·84	12·18	57·02
26	,, Ammoniacal...	8·11	13·13	5·86	44·63	11·05	84·15	9·56	72·81
27	,, ,, ...	6·19	13·29	2·54	19·11	11·62	87·43	8·64	64·55
28	Damaraland ,, ...	6·83	14·63	4·51	30·82	9·76	66·71	8·24	56·32

The order of the solvent power of the solutions is without exception the same as before, viz., (1) neutral, (2) acid, (3) alkaline ammonium citrate.

(*b*) *The action of citric acid solutions.*

As in the case of the citrate solutions, the nitrogenous manures are the more soluble. The order of the solubilities in 2 per cent. solution resembles to some extent the order yielded by the neutral citrate solvent in that the solubilities become less as the total phosphoric acid increases. Here the nitrogenous guanos participate in this regularity, which it will be noticed ceases in the case of the samples richest in phosphates. The same phenomenon is apparent in the results obtained from using the 1 per cent. solution, the only exception being No. 26. With the 0·1 per cent. acid no such regularity is noticeable.

In discussing the solubilities of steamed and other bones in free acid solutions, it was remarked that the solubilities in the stronger acid solvents increased or tended to increase with the total P_2O_5; in the case of the guanos, as noticed above, the tendency is in the opposite direction.

TABLE VIII.

No.	Guano	Nitrogen %	Total P_2O_5 %	Solubility in 0·1 % Citric Acid: Absolute P_2O_5 %	0·1 % Citric Acid: Per cent. of Citric soluble in Total	1 % Citric Acid: Absolute P_2O_5 %	1 % Citric Acid: Per cent. of Citric soluble in Total	2 % Citric Acid: Absolute P_2O_5 %	2 % Citric Acid: Per cent of Citric soluble in Total
21	Peruvian 'Phosphatic'...	2·11	30·45	3·81	12·51	15·17	49·81	21·47	70·50
22	,, ,, ...	1·64	26·13	4·10	15·69	13·73	52·54	18·17	69·53
23	,, ,, ...	1·40	27·28	4·01	14·69	13·66	50·07	18·02	66·05
24	,, ,, ...	2·83	22·64	5·25	23·18	16·54	73·05	19·25	85·02
25	,, ,, ...	3·26	21·36	5·11	24·39	14·91	69·80	18·36	85·95
26	,, Ammoniacal...	8·11	13·13	6·14	46·76	10·60	80·73	12·57	95·73
27	,, ,, ...	6·19	13·29	5·41	40·70	11·95	89·91	12·66	95·26
28	Damaraland	6·83	14·63	6·36	43·47	12·01	82·09	13·10	89·54

It is also worthy of note that, with the single exception of No. 21, the solubilities of the remaining samples in 0·1 per cent. citric acid are in the identical order of their nitrogen contents.

Summary.

With such conflicting results it is difficult to draw definite conclusions. The data are not put forward with that object, but it was felt that there is sufficient interest in the figures themselves to warrant publication. This communication is intended as an interim report on investigations which will be continued as time and occasion permit. However, the general features most worthy of note are as follows:—

(1) The order of the solvent power of the three solutions of each of the two classes remains the same throughout. In the citrate solutions the order is (descending), (1) neutral, (2) acid, (3) alkaline solution, with only two exceptions, viz., the raw bone meals No. 7 and No. 9, discussed under Table III.

With the free acid the solubilities are in the order of the strength of solution without exception.

(2) The presence of free ammonia in the citrate solution lowers the solubility and the amount of lowering varies with different products. To emphasise this a few of the manures were treated with a solution containing 10 per cent. citric acid made strongly ammoniacal and allowed to stand 18 hours at the ordinary temperature. The proportions of phosphoric acid dissolved are set forth in Table IX.

TABLE IX.

No.		Total P_2O_5 %	Soluble P_2O_5 Absolute %	Per cent. of Citrate soluble on Total
4	Steamed Bone Flour ...	28·27	2·21	7·82
6	Bone Meal (raw).........	20·14	0·42	2·08
10	Indian Bone Meal	23·19	0·69	2·98
15	Bone Turnings	25·64	1·18	4·60
18	Fish Meal..................	8·88	1·14	12·83

(3) Bones of similar chemical composition and physical properties, and containing practically the same percentage of total phosphoric acid, have different solubilities in the same citrate or citric acid solution, *e.g.* the steamed bone meals Nos. 1 and 2 (Tables I and II), the bone-sawings Nos. 11, 12, and 13 (Tables III and IV). Moreover, as referred to in discussing steamed bone under Table I, this observation leads one to infer (1) that the action of the solvent is either not one of simple solution, or (2) that there is a fundamental difference in the phosphates of the bones.

In support of the latter alternative is the fact that the samples comparable in chemical and physical properties and with equal percentages of total phosphoric acid show vastly different solubilities in different solutions.

Also this second view is in accord with that of Gebek, who, as mentioned before, in studying the solubility of bone phosphates in citric acid solution concluded that only a small portion of the phosphoric acid of bone exists as tricalcium phosphate, and suggested that the remainder is in the form of dicalcium phosphate and a tribasic phosphate of some organic base. It should be noted that Gebek's method of obtaining his results was by altering the character of the bone previous to treatment with citric acid, a method unlike that by which the results have been arrived at in the present work. It is hoped that subsequent investigations will elucidate this point.

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ON THE QUESTION WHETHER NITRITES OR NITRATES ARE PRODUCED BY NON-BACTERIAL PROCESSES IN THE SOIL.

By EDWARD J. RUSSELL, D.Sc. (Lond.), *South-Eastern Agricultural College, Wye*, AND NORMAN SMITH, M.Sc. (Vict.), *Victoria University, Manchester.*

THE experiments described in the following pages were made with a view to discover how far purely physical and chemical processes, known to take place in the soil, may be expected to give rise to nitrites and nitrates. Scattered throughout the extensive literature on nitrification are occasional papers tending to show, what might also be expected on theoretical grounds, that non-bacterial processes may be important sources of nitrates. Formerly these processes were considered to be the only sources, then came the brilliant researches of Schloesing and Muntz, Warington, Winogradsky, and others on nitrifying organisms, and non-bacterial processes were forced into the background. Now that a full knowledge of the various sources of nitrogen compounds in the soil has become so indispensable to the agriculturist, it seemed desirable to make a careful examination of the various chemical and physical processes known to take place in the soil, and to ascertain whether they make any direct or indirect contribution to its stores of nitrates. To this end we have repeated and extended such of the recorded observations bearing on the subject as seemed to merit repetition; we have also devised other experiments to make the examination as complete as possible.

We have confined ourselves entirely to the possible "fixation" of atmospheric nitrogen and ammonia. The other question, the decomposition of that portion of the nitrogenous matter in the soil supposed to resist the action of bacteria, we have for the present left alone. We have also attempted no measurements of the amount of ammonia the soil takes from the air apart from that actually washed in by the rain.

Our experiments fall into three groups, and deal with the possibility of forming nitrites and nitrates during,

(A) the evaporation of water;

(B) the oxidation of free nitrogen by (1) catalytic processes, (2) induced oxidation[1];

(C) the oxidation of ammonia.

A. THE ALLEGED FORMATION OF AMMONIUM NITRITE DURING THE EVAPORATION OF WATER.

Few, if any of the remarkable observations made by Schönbein have caused more discussion than one published in 1862[2], to the effect that the evaporation of water in air produced ammonium nitrite. It was immaterial whether evaporation took place from metal or earthenware dishes, from wet cloth, paper, or sand; in all cases, Schönbein maintained, nitrogen combined with some of the evaporated water and ammonium nitrite was synthesised. The observation attracted immediate attention, for at that period synthetical processes figured prominently among the chemical questions of the day: Kolbe, Frankland and others were synthesising organic compounds, and Berthelot had only two years previously published his *Chimie organique fondée sur la Synthèse.*

Owing to various causes, among others the absence of delicate characteristic tests for nitrous acid[3], Schönbein's experiments were difficult to carry out, and during the succeeding 20 years discussion was continued, some chemists failing to obtain Schönbein's results, others confirming and extending them[4].

Without going into the details of this discussion it may be noted that interest largely centred round the question whether ammonium nitrite was formed during the distillation of water, or during its rapid evaporation; the slower evaporation taking place at ordinary tempera-

[1] We use the expression "induced oxidation" in preference to "autoxidation" to denote the acceleration of the rate of oxidation of one substance brought about by the simultaneous oxidation of another.

[2] *Annalen Chem. u. Pharm.* 1862, 124, 1.

[3] The Griess-Ilosvay test for nitrous acid was introduced in 1879.

[4] Among the former were Böhlig (*Ann. Chem. Pharm.* 1863, 125, 21); Carius (*ibid.* 1874, 174, 31); Weith and Weber (*Berichte* 1874, 7, 1745); Warington (*Journ. Chem. Soc.* 1881, 39, 229), and Baumann (*Landw. Versuchs. Stat.* 1888, 217); Neumann, *Chem. Centr.* 1890, 665); on the other hand, Zabelin (*Ann. Chem. Pharm.* 1864, 130, 82), v. Loesicke, *Arch. Pharm.* 1879 [3] 14, 58; Scheurer-Kestner (*Bull. Soc. Chem.* 1883; [2] 39, 289); and Schaer (*Arch. Pharm.* 1905, 243, 198) supported Schönbein's contention.

tures was not so fully investigated. It is this slow evaporation, however, which takes place from the soil, and is therefore of chief interest to the agricultural chemist.

In the first series of experiments we repeated the work of previous investigators.

Series I. 1. A fine stream of carefully purified air was drawn through water at various temperatures ranging from 15–18° C. for periods of 14 to 120 hours.

2. Water was allowed to evaporate from a strip of filter-paper hung in pure air.

3. Water was allowed to evaporate from platinum and porcelain dishes kept in well-fitting desiccators. In another series of experiments the drying agent in the desiccator (sulphuric acid) was replaced by water so that evaporation was always counterbalanced by condensation.

4. In the above experiment the surface was increased, and the conditions made to approximate to those obtaining in the soil, by addition of a quantity of ferric oxide.

As a test for nitrous acid we used the Griess-Ilosvay reagent[1], which readily detects 1 part in one hundred million of water. In none of the above experiments, however, did it give the slightest sign of the presence of a nitrite. With so delicate an indicator the experiments are naturally difficult to carry out, the dust, and even the air of a laboratory, contain nitrites, and some samples of glass contain sufficient to give quite an appreciable reaction.

From the description of their experiments given by Zabelin, v. Loesicke, and Scheurer-Kestner, it is quite evident that they failed to exclude these sources of contamination.

Series II. In 1902 Elster and Geitel[2] discovered that soils contain radio-active substances, and their results have been found to hold good both here and in America.

The next series of experiments were designed to discover whether these radiations had any effect in producing ammonium nitrite.

[1] The reagent consists of two solutions, (*a*) 1 grm. of sulphanilic acid ($C_6H_4NH_2SO_3H$) is dissolved in 14·7 grams of glacial acetic acid and 285 c.c. water. This is best done by warming the sulphanilic acid with the acetic acid, to which an equal bulk of water has been added. The remaining water must be added carefully. (*b*) 0·2 gram of α naphthylamine is dissolved in 14·7 grams of glacial acetic acid and 325 c.c. water, taking the same precautions as before. The two solutions are kept separate. 1 c.c. of each is added to the liquid under examination.

[2] *Physikalische Zeitschrift*, 1902, 3, 574: see also Ebert and Ewers, *ibid.* 4, 162.

1. A tube of radium bromide was fixed just above the surface of water evaporating into purified air from a platinum dish contained in a large desiccator. The emanations were of course many times more powerful than those in the soil.

2. An insulated platinum dish containing water was connected with the negative pole of a large Wimshurst machine and maintained at a high potential for some hours. The experiment was conducted out-of-doors in order that the electro-positive ions of the air might travel to the water.

In neither case was any ammonium nitrite found.

Series III. The influence of an electrical field and of sunlight was examined.

1. A platinum dish containing water was connected with one pole of a battery; and a platinum disc, of about the same diameter as the dish, and fixed three inches above it, was attached to the other. A potential difference of 160 volts was maintained for 14 days.

2. Experiments 3 and 4 of Series I. were carried out in bright sunlight during the summers of 1903–4–5.

Again we were unable to detect any trace of ammonium nitrite.

So far as we know, the above include all the conditions obtaining in the soil, and in every case negative results have been obtained. We are therefore justified in concluding that the evaporation even of large quantities of water from the soil does not lead to the formation of any ammonium nitrite.

B. A POSSIBLE OXIDATION OF NITROGEN IN THE SOIL.

This might arise in two ways, by catalytic action or by induced oxidation.

Series IV. Catalytic action. Oxygen and nitrogen readily unite at high temperatures, and the tendency no doubt exists at ordinary temperatures, but is in some way kept in check. In analogous cases reaction can be brought about by catalytic agents, and we have tried their effect here also, selecting platinum, ferric oxide, and soil as the catalysts.

1. Platinum as catalyst. Loew[1] left platinum black mixed with caustic baryta exposed to air for two days, and found distinct quantities of nitrite produced. Owing to the difficulty of carrying out the experiment under perfectly satisfactory conditions we are not in a position to

[1] *Ber.* 1890, 23, 1443.

confirm or deny this statement. Ignited platinum certainly has no such power.

2. Ferric oxide as catalyst. Bonnema[1] claims that ferric oxide can bring about combination, Fausto Sestini[2] on the other hand, that it does not. Our experiments were an extension of those in Series I, 4, and gave entirely negative results, neither ammonium nitrite, nor nitrate being detected[3].

3. Humus as catalyst. Simon[4] states that humus can absorb nitrogen from the air, converting it into ammonia. Prevost[5] showed this was not the case. We also found that in absence of bacteria humus has no power of fixing nitrogen.

4. Soil as catalyst. We have in various ways tried to ascertain whether the soil as a whole has the power of inducing the combination of nitrogen and oxygen, but have failed to discover the slightest indication of any such power. The result of course was more or less to be expected, as it is hardly likely that soil should possess greater catalytic power than ferric oxide.

Series V. Induced oxidation. Many cases are known where the oxidation of one body facilitates the oxidation of another, and in view of the extent to which oxygen is absorbed by the soil it seemed quite possible that this process might facilitate the union of atmospheric nitrogen and oxygen.

(*a*) *Experiments with soils.* There is considerable difficulty in experimentally testing this hypothesis because oxidation in soil is mainly, though not entirely, bacterial; if the conditions are rigidly aseptic so little oxidation takes place that induced oxidation cannot be a factor of importance: whilst if bacteria capable of oxidising organic matter are present any nitrate formed may always be due to their activity rather than to other processes.

It is not, apparently, a difficult matter to kill nitrifying organisms. They cannot withstand an insufficient supply of moisture, and by drying the soil in a steam-oven for some time they are all destroyed.

[1] *Chem. Zeit.* 1903, 27, 149.

[2] *Landw. Versuchs. Stat.* 1904, 60, 103.

[3] For nitrates we used the phenol sulphonic acid test as modified by Wiley, and found it worked admirably. Mix 15 grams of phenol with 92·5 c.c. of sulphuric acid and 7·5 c.c. of water and digest on the water-bath. The solution to be examined is evaporated to dryness on the water-bath, 1 c.c. of the reagent is added, then 1 c.c. of water, the whole warmed and allowed to stand for 15 minutes. It is then diluted to 25 c.c. and made alkaline with ammonia, when a yellow colour appears.

[4] *Landw. Versuchs. Stat.* 18, 452.

[5] *Trans. Chem. Soc.* 1881, 371.

1. 20 grams of soil placed on a large watch-glass were dried at 100° in the steam-oven. The soil was then moistened with 5 c.c. of sterilised distilled water, supported over a large dish of dilute sulphuric acid, and covered with a large bell-jar also standing in the dish. The acid thus forms a lute; air entering as the result of changing temperature or pressure has first to pass through the acid where any ammonia would be retained.

2. Another 20 grams were dried at the same time in a weighing bottle and kept dry.

After 20 days the nitrite and nitrate were estimated in both soils. We found it more convenient in dealing with soils to discontinue the colour tests, and to determine the nitrite and nitrate by the usual reduction method after previously removing all the ammonia present.

Soil	Nitric N, before experiment	Nitric N, after experiment	Difference, parts per million of dry soil
Old chalk pasture, dried 15 hours...	7·5	37·5	30
Rich garden soil, dried 2 hours......	8	10	2
Alluvial pasture soil, dried 2 hours.	5	9	4

Apparently all possibility of bacterial action is out of the question and the increase in nitrates must be due to purely chemical causes. The conditions, however, are not really aseptic. Tested in the apparatus described in a previous paper[1], the soils showed after prolonged drying at 97°, and subsequent moistening with sterilised distilled water, a considerable capacity for taking up oxygen. As all the micro-organisms do not seem to have been killed, the results may be explained in three ways:

(1) nitrifying organisms may have been present;

(2) there may have been some organisms, differing from the ordinary nitrifying organism, producing nitrate from the nitrogenous substances present;

(3) induced oxidation may have taken place.

(1) seems unlikely; (2) is not improbable, in fact Fraps[2] has obtained evidence of the existence of organisms capable of producing nitrates direct from organic matter; (3) is also probable. There seems to be no way of directly deciding between the second and third hypotheses, but

1 This *Journal*, Part 3, p. 261.
2 *Amer. Chem. Journ.* 1903, 29, 236.

the indirect evidence adduced later on is very clearly against induced oxidation.

When antiseptics were added to the soil no increase in the nitrates could be detected, even after three weeks' exposure to pure air.

Soil	Nitric N, before experiment	Nitric N, after experiment	Difference, parts per million of dry soil
Wye hop garden + ·04 °/$_0$ $HgCl_2$......	50	49	−1
Old pasture (Gault) + chloroform ...	25	25	*nil*

(*b*) *Experiments with pure substances.* This is by far the most satisfactory method of testing the induced oxidation hypothesis, since complications arising from bacterial action are entirely avoided.

For the earliest recorded observations on the production of ammonium nitrite and nitrate during oxidations we have again to go back to Schönbein, who stated that these bodies arise when phosphorus oxidises in moist air. Subsequent workers have confirmed this statement[1]. It has also been said that ammonia is produced during the rusting of iron, and that traces of nitric acid are formed in the slow oxidation of ether[2].

We have made a number of experiments with pure substances, but, as they are only of indirect interest for our present purpose, and as an account of them is appearing elsewhere, it is only necessary to very briefly state the results. The method of experiment was essentially the same as for the soils, but we reverted to colour tests, owing to their greater sensitiveness. The substances investigated were of the most varied description, and comprised phosphorus, sodium, potassium, magnesium, calcium, zinc, tin, iron, manganous hydrate, ferrous hydrate, cuprous oxide, and cuprous chloride. In many experiments we found traces of ammonium nitrite, or nitrate, but in no instance did the total amount of nitrogen thus combined exceed ·005 milligram for about 5 grams of substance oxidised. Even if the whole of this nitrogen had come from the atmosphere and been oxidised by induced oxidation processes we should only have about 1 part of nitrogen "fixed" for every million parts of oxygen absorbed. A quantity of this order of magnitude

[1] Cf. Berthelot, *Ann. de Chimie*, 1877 [5] 12, 440.

[2] Cf. Berthelot, *Comptes Rendus*, 1889, 108, 543. The idea that ammonia is produced when moist iron and zinc are allowed to stand in air was commonly held at one time, see Gmelin's *Handbook*, Vol. 2, p. 417.

is manifestly negligible, and we may dismiss the hypothesis that induced oxidation of nitrogen takes place in the soil.

C. OXIDATION OF AMMONIA IN THE SOIL.

The percentage of ammonia in the air is exceedingly minute, but the absolute quantity coming in contact with an acre of soil during the year must be fairly considerable. It is not yet known how much of this is actually absorbed, determinations made by exposing sulphuric acid to the air[1] have indicated about 40 lbs. per acre per annum, but these results are not entirely applicable to soil-absorption.

Apart from bacterial action, oxidation may proceed in two ways, by catalytic action and by induced oxidation, and each has been made the subject of experiment.

Series VI. Catalytic action. The extensive literature dealing with this subject need not be referred to here. As an example of the investigations carried out in this direction we may mention one paper by Fausto Sestini[2], who showed that moist ferric oxide will at ordinary temperature bring about the oxidation of ammonia, and he concludes that this reaction takes place in the soil.

Soil	Nitrate present after 2 weeks' exposure to		Difference, parts per million of dry soil
	pure air	air mixed with NH_3	
Light sand (Lower Greensand)	10	10	0
Chalky loam + ·05 °/₀ phenol	57·5	57·5	0

1. About 10 grams of ferric hydrate, washed free from all traces of nitrous and nitric acids, were exposed in the apparatus already described (p. 449) to an atmosphere containing ammonia for 10 days[3]. When the ferric oxide stood in a glass vessel distinct quantities of nitrite and nitrate were obtained, but when we used a platinum vessel much less was produced. If ammonia solution is allowed to stand in contact with glass it will usually dissolve out in quite a short time sufficient nitrite

[1] Collard de Martigny (*Journ. de Chimie Médicale*, 1827, III. 517) was one of the first to make the experiment in this way.

[2] *Landw. Versuchs. Stat.* 1904, 60, 103.

[3] This was secured by placing in the apparatus a small dish of concentrated ammonia solution, which was renewed from time to time.

to give a distinct reaction with the Griess-Ilosvay solution; and we think the high results obtained by Sestini are in part due to the fact that he used glass.

2. The experiment was repeated with manganese dioxide, lead dioxide, and stannic oxide, and in each case a slight oxidation of ammonia took place, amounting, however, only to ·01 – ·1 milligram in 3 or 4 weeks.

3. 20 grammes of a sandy soil (Lower Greensand) known not to undergo much oxidation was next exposed to the ammoniated atmosphere. In other experiments a rich loam, sterilised with ·05°/₀ phenol, was used.

Evidently no oxidation of ammonia has taken place.

Series VII. Induced oxidation of ammonia. It has long been known that ammonia not only favours the oxidation of metals with which it is in contact, but is itself oxidised during the process; this is notably the case with copper, and, to a less extent, with zinc, and tin, with manganese and ferrous hydroxides, and with phosphorus. In fact ammonia oxidises far more readily in this way than by a catalytic action. Some difficulty arises in dealing with soils; nitrifying organisms must be removed and yet oxidation must be allowed to take place.

Soil	Nitrate present after 3 weeks' exposure to		Difference, parts per million of dry soil
	pure air	air mixed with NH_3	
Old Chalk pasture soil (dried 15 hrs. at 95°)	37·5	40	+2·5
Alluvial pasture soil (dried 2 hours, at 95°)	9	7	−2
Old pasture (Gault) treated with chloroform	25	44	+19
Hop garden, Wye	62·5	75	+12·5

In no case is bacterial action excluded: presumably nitrifying organisms would be destroyed by heat or by chloroform, and even if they were not, an atmosphere saturated with ammonia would probably be unfavourable to their activity.

We found by direct experiment that the soils still vigorously absorbed oxygen after being heated or treated with chloroform, the conditions were therefore favourable for induced oxidation. In the alluvial pasture soil it did not take place, in the Gault it apparently did.

There is some uncertainty about the Chalk pasture and about the hop garden soils, the latter was not treated in any way and contained nitrifying organisms.

It seems quite probable that some nitrate may be formed from ammonia in the soil by this process.

Conclusions.

Taking the results as a whole we find they are conclusively against any measurable formation of nitrites or nitrates in the soil from atmospheric nitrogen or ammonia by chemical or physical processes.

The first series of experiments shows that in no circumstances does the evaporation of water produce ammonium nitrite.

Oxidation of free nitrogen might theoretically be expected to take place in the soil either by catalytic or by induced oxidation processes. There is considerable difficulty in testing the latter hypothesis owing to bacterial complications, but the indirect evidence adduced from experiments with pure substances shows that if induced oxidation takes place at all its effects are so extremely slight that in practice they would be altogether negligible.

Catalytic oxidation of nitrogen does not seem to occur in the soil.

Slightly different results were obtained with ammonia. As the higher oxides of iron and manganese possess a slight power of catalytically oxidising ammonia, it might be expected that soils in which they occur to any extent would possess the same power; in any case, however, the effect is only small, and appears to be of no practical consequence.

On the other hand, ammonia oxidises more readily in presence of other substances undergoing oxidation. Experiments with soils showed that this induced oxidation may, under certain rather artificial circumstances, come into play as a factor in producing nitrates; but it must be remembered that at the low partial pressures of ammonia obtaining in nature, bacterial nitrification would be more prominent than in our experiments. Taking this point into consideration, the induced oxidation of ammonia cannot be regarded as an important source of nitrates under natural conditions.

SOME PRELIMINARY NOTES ON THE PHYSICAL PROPERTIES OF THE SOILS OF THE GANGES VALLEY, MORE ESPECIALLY IN THEIR RELATION TO SOIL MOISTURE.

By H. M. LEAKE, M.A., F.L.S.,

Late Scholar, Christ's College, Cambridge.

INTRODUCTION.

IN a stretch of arable lands like those of the Ganges Valley, although damage may be caused by occasional floods, which are sudden and of short duration, the more general, and by far the most serious loss is due to deficiency of moisture of the soil: thus the relation of the soil to soil moisture becomes of more than ordinary importance. Dr Voelcker[1], in his Report on Indian Agriculture, remarks: "In India the relation of soils to moisture acquires a greater significance than almost anywhere else......" This relation is fundamental, for on it depends the methods for the conservation of soil moisture, for the economical application of irrigation water, and for the treatment of barren and salt lands—all problems of direct interest to agriculturists in the plains of Northern India. The methods for dealing with these problems must be largely—if not entirely—empirical until such time as the behaviour of the soil in its relation to moisture is investigated. The problem in all its various branches is enormous, and in a country in which the seasons follow each other with such rapidity, and vary the one from the other in so marked a manner, it frequently happens that a particular point, if not determined within a period of a few days, must await solution until the following year. It is impossible, therefore, that a series of observations covering a period of barely twelve months should be other than of a purely preliminary nature, and it is in full recognition of this fact that they are here given. Further work will be necessary before it can be

[1] "Report on the Improvement of Indian Agriculture," 1893, p. 42.

considered proved that what is here put forward as a possible explanation of the observed facts is in reality the true explanation. For the present it can merely be stated that the experimental evidence points to the probability of the relation to be indicated.

Although the climate and usual methods of cultivation are matters of common knowledge, it will, for several reasons, be convenient to give a brief survey of the main features of the districts under consideration. These accounts are in no sense exhaustive, and in some cases even, some of the main features are omitted. They will serve, however, to emphasise those points to which the present experiments have reference.

The chief line of enquiry has been that of the relation of soil to soil moisture. Certain preliminary determinations are, however, necessary for the interpretation of results, and since the soil differs so materially from the common types of England, the Continent, and America, on which the major portion of the work on soils has been done, it seemed preferable to re-determine these for the actual soils under consideration[1]. These determinations are here given. One, however, and possibly the most important, namely, mechanical analysis, has to be omitted until such time as opportunity offers for making the necessary determinations. It may be noted in this connexion that in alluvial soils like those under consideration, with little organic matter, and in which the ultimate particles are so minute, mechanical analyses will in all probability prove of more than ordinary importance.

Weather. The main features of the weather are best considered under the three separate headings of (1) Rainfall, (2) Temperature, and (3) Humidity.

Rainfall. In addition to indicating the essential characteristics of the normal season, the following table notes the peculiarities of the particular season under consideration:—

[1] For similar reasons the references to the somewhat bulky literature which has been consulted have been omitted.

(1) *Rainfall.*

	Average[1]		Actual figures for period under observation[2]	
	Rainfall in inches	No. of rainy days	Rainfall in inches	No. of rainy days
April	0·69	6·3	0·00	0 } 2
May	2·59		0·35	1
June	7·66	49·4	3·20	5 } 35
July	12·13		5·65	2
August	12·24		9·45	12
September...	9·33		3·35	10
October	2·80		4·20	6
November ...	0·07	0·5	0·00	0 } 0
December ...	0·11		0·00	0
January......	0·65	2·4	0·35	1 } 2
February ...	0·45		0·10	1
March	0·37	—	0·10	1
Total......	49·09	58·6	26·75	39

[1] From *Indian Weather Review*, 1902.
[2] Author's determinations.

A sharp division into a period of rains—June to October—and a dry period—October to June—is the chief characteristic. The rainfall during the dry period is far too little to support growth in itself. The growth which takes place throughout the greater portion of the year is therefore dependent on the moisture which the plant can derive from the soil. The particular year under consideration is characterised by the lightness of the monsoon rains. This is a factor which must be taken into consideration in considering the values given below; but it seems improbable that the conclusions here drawn will be rendered invalid on this account.

(2) *Temperature* (° F.).

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Maximum...	72·7	76·8	87·9	96·1	95·6	92·4	89·5	88·5	88·3	86·7	81·3	74·5
Minimum...	52·1	54·4	62·9	71·9	76·3	79·2	79·8	79·3	78·8	73·1	62·0	53·7

The above table[1], giving the monthly means of the maximum and minimum temperature, illustrates the main features with regard to the temperature. If this table be compared with that already given for the rainfall it is seen that there are three strongly-marked seasons which may be arranged as follows:—

(1) Cold weather......mid-October to March—low temperature, dry.
(2) Hot weather......March to mid-June—very hot and very dry.
(3) Rains...............mid-June to mid-October—hot and wet.

(3) *Humidity.*

The table given below[2] simply emphasises the conditions which are prevalent during the hot weather:—

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
71	63	54	52	62	76	83	84	82	75	70	73

The Relation of the Soil to Crops. It is not proposed to do more than touch upon this subject; and the point that it is most desired to bring out is best indicated in the case of indigo. In Behar, indigo is commonly sown in early March, when, from the table of rainfall, it will be seen that over four and a half months of practically rainless weather have preceded the time of sowing. Nevertheless, seed placed not an inch below the surface and without irrigation, will germinate. Nor is this the only point, for the young plant is capable of living and growing throughout the three intensely hot and dry months immediately following. Frequently this period passes without a drop of rain, and the plant is subjected during the day to the scorching west winds that are prevalent at this season.

Some idea of the conditions to which the young plant is subjected is given in the following table of soil temperatures:—

[1] From *Indian Weather Review*, 1902.
[2] From *Indian Weather Review*, 1896.

Soil Temperature (° F.)[1].

	Surface	2 inches	6 inches	12 inches
Germinative period:—				
2 p.m. March 20th	121	86	73·5	69·8
Average for week— 2 p.m. March 17th—March 23rd	117	84·5	72	69
Period of greatest heat:—				
2 p.m. May 17th..............	143·5	102	91·5	86
Average for week— 2 p.m. May 14th—May 20th ...	138	102	92	87

A soil, in which not only will seed germinate, but which will support the young plant throughout the protracted period of intense heat and drought, must bear some peculiar property in its relation to moisture.

Methods of Cultivation. Here again the methods of indigo cultivation best indicate the desired points. In the case of this crop the cultivation is most thorough. Briefly, it is as follows:—

The land is thoroughly ploughed two or three times about the middle of October (immediately after cessation of the rains).

If the land be at all "heavy," the clods of earth are, in addition, thoroughly broken by hand, and in this way the surface soil is rendered exceedingly fine. It is then subjected to a process of compacting by means of a *maira*, a native implement which takes the place of a roller, and consists of a flattened log, to the two ends of which bullocks are yoked. The land is thus compacted at frequent intervals until the sowing period in early March. The moisture is by this time drawn up to the surface, and the seed is drilled in and pressed home by passing the *maira* again over the field. Germination takes place in 7—10 days. This method is entirely empirical on the part of the cultivator, but it seems worthy of some enquiry and explanation, for it is a remarkable fact that so much moisture can be brought to the surface in this way by the single process of compacting.

General Physical Properties. The soils which form the subject of the present note occupy an area of considerable extent, covering as they do a stretch of country some 800 miles in length, with a breadth varying from 50 to 150 miles. Throughout this area there is an unbroken stretch of alluvial lands, traversed by numerous rivers, which, after

[1] Author's determinations. The complete series will be found in the "Report of the Dalsingh Serai Research Station, 1905."

leaving the hills, have a fall of between 6 and 9 inches in the mile. The beds of these rivers are some 20 feet below the general level of the surface, which latter extends for mile upon mile in a slightly undulating manner. The undulations are, however, very slight, and rarely reach a value of 10 feet. The depth of alluvial soil is, throughout the area, very considerable, and over the entire area extends below the level of the ground water. In texture the soil is remarkably fine, and broken only by stretches of a calcareous deposit known as *kankar*. These deposits occur quite irregularly, and at various depths. In the absence of mechanical analyses it is impossible to give any accurate measure of the size of the soil particles. It is known[1] that 97—98 per cent. of the soil will pass through a sieve with 80 meshes to the linear inch. A more abstract, but, perhaps, a more lucid, idea will be given, if it is said that thê ultimate particles are so minute that, if rubbed dry between the fingers no sensation of "grit" is produced. Until definite mechanical analyses are made this description must suffice. As is usual with alluvial soils, considerable variation of character occurs, and the changes are frequently abrupt and quite irregular. Thus beds of clay occur which rapidly die out and may be replaced by a fine, light sand or by some intermediate type; but the point that it is desired to emphasize is, that all these variations take place within the limits of size of the soil particles above given.

(2) SCOPE AND METHODS OF THE INVESTIGATION.

At the commencement, the scope of the investigation was strictly limited to the determination of the moisture and temperature of the soil for the normal conditions under which indigo is sown, with the ultimate object of tracing some means of rendering these as favourable as possible; for, although the crop is normally sown at this season, a fact which, in itself, proves that germination is, as a whole, satisfactory—it is undoubtedly the case that a considerable annual loss takes place from failure in the germination or from subsequent withering due to lack of moisture.

It was soon found, however, that the moisture conditions were subject to such daily and seasonal variations that the scope had to be widened considerably to include a study of the causes which gave rise to these variations. Here, again, it was found impossible to draw a limit, and it became necessary to study in outline the general question

[1] Determination made by author.

of the relations of the soil moisture to the ground water, and of this, again, to the free water surfaces. It was found, for instance, that a considerable movement of the soil moisture was taking place, and that this movement was of such a nature that it must constitute a severe drain upon the reserve supply of ground water. A daily record of the fluctuations of a well was therefore instituted. The fluctuations so disclosed seemed barely sufficient to account for the observed facts, and a further comparison was made between the well level (level of ground water) and that of the free water surfaces (river, etc.). The gradually expanding scope of the investigation, taken in conjunction with the short period devoted to the enquiry, necessarily led to a somewhat limited collection of data. They, however, point to the probability of several hitherto unrecognised conditions—possibly peculiar to these soils—the recognition of which, it is hoped, may help to a solution of some of the problems connected with them.

Methods. As the general texture of these soils admits of the employment of somewhat unusual methods in the determination of the various properties now to be considered, those methods finally adopted must now be considered in some detail.

Samples were all taken by means of an iron cylinder about 4½ inches in diameter, fitted loosely with an iron piston, which allowed the cylinder to be driven in to a depth of 8 inches exactly. The soil to one side of the cylinder is then removed, and the 8 inches column of soil isolated by the insertion of a *khurpa* (a flat trowel), and removed to the laboratory.

Soil moisture is now determined in the following manner:—In a cylinder of the above diameter the soil can be readily removed by means of the piston without appreciable compression of the superficial layers. One inch (the eighth inch) is first removed, and the soil rapidly and thoroughly mixed in a mortar. From this mixed soil approximately 10 grams is removed into a small glazed porcelain dish, which has been previously dried and weighed, and the weight accurately determined. A second sample, similar to the first, is taken in like manner.

A second inch is now removed and duplicate samples taken of it, and this process is repeated with each of the superficial eight inches contained in the original sample. This method of duplicate determination, therefore, gives 16 samples. The series of dishes is now transferred to a water-oven at 100° C., which is maintained at that temperature for from 4½ to 5 hours. The dishes are then removed to

a desiccator, cooled and weighed, after which they are again heated for 3 hours, and again cooled and weighed.

With regard to this procedure the following points may be noted. It is a procedure which relies solely on the minute size of the soil particles for its accuracy and practicability. That remarkably accurate results are obtainable will be apparent from the figures noted throughout this paper. It will be sufficient to give here two examples of the degree of accuracy obtainable.

DEGREE OF AGREEMENT BETWEEN SAMPLES.

The following figures are chosen to show the range of accuracy obtainable, and are typical of the degree of error admitted:—

	Weight of moisture per 100 grams dry weight of soil					
	1	2	3	4	5	6
Sample No. 1 ...	17·31	14·84	12·02	16·64	19·90	5·83
„ No. 2 ...	17·31	14·92	12·11	16·55	20·12	5·50
Difference	0	0·08	0·09	0·09	0·22	0·33
Percentage error	0	0·5	0·8	0·5	1·1	5·7

The first five examples here given are typical of the errors accepted. An error, such as that given in the sixth example, is only accepted in the few cases where the determination was of a superficial layer of loose, almost dry soil. It is obvious that the same actual error is trebled when the percentage moisture falls from 15 to 5; moreover, such a dry soil consists largely of aggregates which are not readily broken down, and the loss of moisture which would take place during the time occupied in producing a thoroughly homogeneous mixture, will introduce a larger error than is now under consideration.

THE WEIGHT OF DRY SOIL CONTAINED IN THE CYLINDER.

The total initial weight of the soil was determined by actual measurement, and the percentage moisture in each inch was then determined, and, from these, an average figure for the percentage moisture obtained. From these figures a simple calculation gives the

dry weight. The following table gives the most divergent results obtained in numerous determinations:—

	Date	Actual weight	Average moisture	Dry weight	Difference	Percentage error
1st determination	Dec. 4	2522	10·94	2245·5	34·5	3·6
2nd ,,	,, 23	2573	10·01	2329·0		

The method, owing to its indirectness, is not one that admits of general adoption, and the chief reason for its use was the comparative ease with which small samples can be handled. Its accuracy is nevertheless sufficient, for it must be noted here that the land had twice during this season been "compacted," a process which must naturally raise the weight of soil in the superficial 8 inches. The error due to the method of experiment and calculation is therefore certainly less than that given.

The second point to be noted in this procedure is the use of the temperature of 100° C., for drying. This was adopted in place of the more usual 110° C., as a matter of convenience. Preliminary experiments had shown that the increased loss due to the use of the higher temperature did not exceed 0·005 gram on 10 grams soil.

Details of the Investigation.

(A) *Specific Gravity.* This was determined from samples of soil dried in the following manner:—

The soil is first air dried and then reduced to fine powder in a mortar, after which it is dried in a water-bath of 100° C., for four hours. It is then cooled in a desiccator and transferred to a dry tube when cool.

A known weight of about 10 grams of this soil is boiled with water in a small flask. After cooling to 60° C., it is transferred to the specific gravity bottle and weighed.

Each determination is controlled by a second determination in which an unknown weight of soil, prepared and boiled as before, is transferred to the specific gravity bottle. The bottle is weighed and the contents are then transferred to an open dish, evaporated to dryness over a water-bath, and finally dried for four hours at 100° C., in a water oven. The dish is then transferred to a desiccator, cooled and weighed. The two figures in all cases agree within an error of 1·5 per cent.

A series of determinations was thus made for each of the eight superficial inches, and the average of the duplicate determinations is here given:

Specific Gravity.

	Surface to 1 inch	1—2 inch	2—3 inch	3—4 inch	4—5 inch	5—6 inch	6—7 inch	7—8 inch
Specific gravity ...	2·716	2·715	2·713	2·710	2·706	2·736	2·734	2·734
Average ...	2·713				2·735			

The chief point of interest in the above table is the abrupt rise of specific gravity below the 5th inch, the increase being 0·022. So far no recorded parallel has been traced. The cause may possibly be found in the native plough, which penetrates to this depth. At least once each year the lands are thoroughly ploughed several times in each direction, but the soil is not inverted. It is possible to conceive that this repeated loosening accompanied by percolation of rain would silt out the particles of higher specific gravity from the superficial soil.

(B) *Apparent Specific Gravity.* For this determination a cylinder of known internal diameter and 8 inches in length was used. The methods by which the dry weight of soil contained in the cylinder was determined have already been detailed and need not be repeated here. From this figure the apparent specific gravity of the superficial 8 inches of soil is readily calculated. In these determinations a break is apparent at the 4th inch, showing the more compact nature of the soil below that depth. It will be convenient, however, to consider the superficial 5 inches together, since, as has already been shown, the increase in the actual specific gravity occurs here.

The following figures will indicate the range of value obtained for the apparent specific gravity:—

	8 inch—6 inch		5 inch—top		Total, 8 inch—top	
	Dec. 4	Dec. 23	Dec. 4	Dec. 23	Dec. 4	Dec. 23
Total weight (gr.)	996	1024	1526	1519	2522	2573
°/₀ moisture	11·71	12·63	10·48	7·40	10·94	10·01
Dry weight (gr.)..	879·37	894·67	1366·07	1434·37	2245·44	2329·04
Volume (c.c.) ...	649·99		1091·85		1741·84	
Sp. g. (apparent)	1·351	1·376	1·255	1·315	1·302	1·345
Difference	0·25		0·52		0·43	
°/₀ error...........	1·8		4·0		3·2	

As has been already explained, these differences are, at least partly, due to the cultivation of the field during the intervening three weeks. A control determination, taken on Dec. 4th, gave the total dry weight as 2237·4, and the specific gravity (apparent) as 1·284, or a working error of 1·4 per cent.

(C) *Weight of Soil per Acre.* This is merely a calculation from the apparent specific gravity. For these lands the weight of dry soil per acre of a layer 8 inches deep is approximately 2,400,000 lbs. The exact value for the superficial 8 inches will, of course, depend to some extent on the condition of cultivation. Thus in the sample taken on Dec. 4th the value is 2,360,253 lbs., while that for Dec. 23rd is 2,438,423 lbs., the mean being almost exactly 2,400,000 lbs., which figure may be taken as the average weight of soil in an acre calculated as 8 inches deep.

(D) *Volume of Interstitial Space.* The figure representing the volume of the interstitial space is most important, since it will indicate the maximum volume of water which could be contained in saturated soil. For this reason the value should be calculated from the values obtained for the 6th—8th inch inclusive. These will approximate more nearly to the true value for the bulk of the soil. Calculated in this manner the most divergent values obtained were:—

$$\left.\begin{array}{l}(1)\ \ 50{\cdot}3\\(2)\ \ 49{\cdot}4\end{array}\right\}\text{ average } 49{\cdot}8.$$

Roughly, therefore, the interstitial space may be considered as equal to one-half the volume of the soil.

(E) *Saturation Value.* By this is meant the number of grams of water contained in the saturated soil, the dry weight of which is 100 grams. Throughout the following pages the figures representing moisture percentages are calculated on the dry weight. This value has not been determined experimentally, it can, however, be readily calculated from the above figures. It has been shown that the interstitial space is approximately 50 per cent., while the specific gravity (actual) of the soil is 2·755. This is equivalent to 36·6 per cent. moisture on the dry weight of soil.

(F) *Movement of Soil Moisture.* This question is a very wide one, and the determinations now detailed only touch on the very margin of the subject. They seem, however, to indicate that this movement assumes very large proportions in these soils. The methods by which the determination of the value of soil moisture was made have already

been detailed. It will be necessary here, therefore, only to note the general mode of investigation.

The experiments consist of two series which were carried out concurrently. In the first of these a particular area of land was submitted to various methods of culture, and the effect of these on the moisture content of the superficial 8 inches determined from samples removed at intervals. This series was commenced immediately after the cessation of the rains in October, and continued until the following February.

In the second series the moisture in the land at different stages of cultivation was determined (*a*) in the early morning, (*b*) about 2.30 p.m., the two samples in all cases being taken as near as possible to each other to reduce to a minimum the errors introduced by lateral variations in the value of soil moisture.

Clearly the first point to determine is the behaviour of moisture in uncultivated land. For this purpose a field was, shortly after the commencement of the rains, allowed to go out of cultivation after a preliminary course of thorough ploughing and levelling. In this condition it remained until the end of the rains, and received the last rain on October 7th to 9th, between which dates 2·85 inches of rain fell.

Moisture determinations were made on the following October 10th, and again on October 17th, October 23, and November 21st, the only rain received during the period was 0·3 inches, which fell on October 30th; the field throughout the period remained untouched.

The following table shows the values obtained:—

Percentage of Water in Soil Samples.

	8th inch	7th inch	6th inch	5th inch	4th inch	3rd inch	2nd inch	Top inch
Rains ended Oct. 9th								
Determination of Oct. 10th	21·75	20·97	20·60	20·01	20·57	20·59	20·94	21·12
,, ,, ,, 17th	19·56	17·27	15·37	14·35	13·29	13·33	12·29	9·35
,, ,, ,, 23rd	19·23	16·33	14·14	12·62	12·21	11·91	11·07	8·96
,, ,, ,, 30th	0·3	rain fell	—	—	—	—	—	—
,, ,, Nov. 21st	13·23	13·18	13·32	11·85	9·83	9·00	8·13	5·84
Loss during period Oct. 10th—Nov. 21st	8·52	7·79	7·28	8·16	10·74	11·59	12·81	15·20
Average loss......10·26								

This is equivalent to a total loss of 210 tons of water per acre, or an average daily loss of 4 tons per acre.

That this figure should represent the actual loss per acre during the period is highly improbable, and an attempt was accordingly made to obtain a nearer approximation to the real value.

The percentage of water at a given point is never stationary, and its amount must be considered as the value which results from the simultaneous action of two natural causes, (1) the motion from that point in the direction of the surface, to replace the water removed by the evaporation influence of the air, and (2) the passage of water to that point from a lower level. It must be borne in mind that these processes may be reversed as the result of heavy rain, and the motion will then take place in the opposite direction. The following table will, however, show that in these soils the important motion is that given above. On the 23rd October two determinations were made: the first of these from a sample taken at 8 a.m., at which time evaporation had barely commenced, the second from a sample taken at 2.30 p.m., shortly after the heat of the day had passed and when evaporation might therefore be supposed to have reached a maximum:

Percentage of Water in Soil Samples.

	8th inch	7th inch	6th inch	5th inch	4th inch	3rd inch	2nd inch	Top inch
Morning sample	19·23	16·33	14·14	12·62	12·21	11·91	11·07	8·96
Afternoon sample	15·60	14·39	12·74	12·21	12·11	11·39	9·86	4·93
Loss.........	3·63	1·94	1·40	0·41	0·10	0·52	1·21	4·03

It will be evident from this table that the moisture lost during the day is replaced from below, in greater part, during the night.

The table also gives a close approximation to the correct value of the total daily loss. It is equivalent to a loss of 1·66 per cent. of dry weight, or 17·8 tons per acre. This is very much in excess of the figure previously obtained, and indicates a considerable recuperative power.

This figure, again, cannot be considered more than an approximation, and it is not yet apparent what the true value of the daily loss is. The following reasons briefly indicate that the loss must be in excess of this figure:—

(1) The figure obtained is the actual loss only, it must be remembered that the upward motion of the water is a continuous process

which only becomes apparent at night, when evaporation is slight or non-existent.

(2) The second (afternoon) is taken at 2.30 p.m., when evaporation is at its maximum. Evaporation will not cease till evening (about 6 p.m.), and this latter amount is omitted from the calculation.

(3) From the above figures it is obvious that the loss is not restricted to the superficial 8 inches, and, probably within a short distance, it would appear to be increasing with the depth.

There is here sufficient reason for supposing that, in taking the above figure—17·8 tons per acre—as the daily loss, the calculations based on it will not be open to the charge of exaggeration.

It is apparent from the figures given here that there is in these soils an enormous capability for raising water to the surface, though it is not possible at present to give an exact measure of it. The recognition of this upward motion is so important that a further proof of its existence will be given.

It has already been shown that a field, which is not tilled, rapidly and consistently loses moisture. The cause of this is to be found in the fact that there is a complete continuity of soil particles up to the surface. There is no abrupt rise in the volume of the interspaces such as occurs about the 5th inch when the land is cultivated with the native plough. Consequently the flow of moisture from below to the surface receives no check. The effect produced by introducing such a break in continuity was the next point of enquiry. For this purpose the field was put under the system of cultivation normally adopted when indigo is to be sown, and which has been briefly described above. The field, which had up to November 21st remained untilled, was ploughed and levelled with the *maira* on 22nd, and again compacted with the *maira* on December 22nd and the moisture determined. Though the cultivation was delayed until very late, and the land had in the meanwhile been allowed to lose a large amount of the original moisture, it was by this time approaching the condition of indigo lands. These figures are now given:—

Percentage of Water in Soil Samples.

	8th inch	7th inch	6th inch	5th inch	4th inch	3rd inch	2nd inch	Top inch
Determination of Nov. 21st	13·23	13·18	13·32	11·85	9·83	9·00	8·13	5·84
,, ,, Dec. 22nd	15·14	14·19	14·11	11·72	9·66	8·20	7·23	3·54
Gain or loss	+1·91	+1·01	+0·79	-0·13	-0·17	-0·80	-0·90	-2·30

The result of cultivation has been a total loss equivalent to 0·07 per cent. of dry weight from top 8 inches. The figures, however, show that the loss is confined to the superficial 5 inches as the result of loosening the soil. Below this there is a marked rise, the value of which increases with the depth. The condition of the field is obviously much more satisfactory, but the chief point to be noticed is that the increase is due to a rise of moisture from the lower layers of the soil.

An examination of the figures for December 22nd shows no marked break in the diminution of soil moisture as the surface is approached. The diminution is gradual, and requires a comparison with previous figures to make the break at the 5th inch apparent. It appeared, therefore, that an effective break had not been introduced, and a further attempt was made to do this. For this purpose the land was ploughed four times, and finally a *maira* lightly run over the surface to level without compacting the soil. The surface soil was reduced in this way to a very fine and practically air-dry condition, which, it was anticipated, would form an adequate check to evaporation. On the morning of January 18th, rain began to fall, and a sample was therefore taken and a moisture determination made. Previous determinations are quoted for comparison:—

Percentage of Water in Soil Samples.

	8th inch	7th inch	6th inch	5th inch	4th inch	3rd inch	2nd inch	Top inch
Dec. 19th, field ploughed and levelled								
Determination of Dec. 22nd	15·14	14·19	14·11	11·72	9·06	8·20	7·23	3·54
,, ,, Jan. 18th	21·58	16·23	13·80	10·85	9·33	7·27	4·36	7·52
Gain or loss	+ 6·44	+ 2·04	- 0·31	- 0·87	- 0·83	- 0·93	- 2·87	+ 3·98

Here, again, the superficial inches show a loss (the gain in the top inch being due to a rain falling at the time the sample was taken). The 7th and 8th inch, however, show a large increase in the moisture content, equivalent to 4·24 per cent. of the dry weight. This rise is due to the reduction of evaporation, which is now so small that the upward flow can more than compensate for it. It must further be noted that the moisture contained in the 8th inch is now equal in amount to that contained by this inch the day after a three days' rain had ceased. In the meantime three months had elapsed, broken only by a single shower of 0·3 inches—three weeks after the commencement of the experiment.

If there be needed further proof of an upward flow which is capable —in the presence of only slight evaporation from the surface—of maintaining the moisture at a value which is 60 per cent. of the saturation value, and, in the presence of excessive evaporation, very largely replacing during the night the moisture lost by evaporation during the day, it will be found in the fact that it became possible by altering the methods of cultivation, to reduce and increase at will and within wide, but so far indefinite, limits the moisture in the field. Sufficient has, however, been said to show that an upward flow of no mean order appears to be the rule in these soils.

From the figures given in the above lines it is apparent that there must be a drain of no mean order upon the moisture retained in the soil, and it becomes a matter of interest to trace to its source the supply from which this movement emanates. To a small extent, data bearing upon this problem have been accumulated. Though suggestive, their range is necessarily small, and insufficient to throw any very direct and definite light upon the subject. These preliminary notes upon one branch of the problem are now communicated in anticipation of the occurrence of an early opportunity for a renewal of the investigation upon the wider aspect. Until such opportunity occurs for dealing with this more fully the data and their interpretation must remain incomplete.

CONCLUSION.

The points on which an attempt has been made to lay emphasis may be summed up as follows:—

(1) A large daily evaporation is taking place from the surface of the soil.

(2) This evaporation is entirely, or in greater part, counteracted by a large upward flow of moisture from a lower level and ultimately from the ground water.

Sufficient has been said throughout the course of the paper to show that the question is one of considerable practical importance, and it is unnecessary to dilate further on this aspect. Further work will alone decide the questions which have been indicated; possibly the more serious omissions in the above series of observations are to be found in the absence of mechanical analyses, and in the complete lack of observation of the value of soil moisture at a greater depth than 8 inches.

MECHANICAL ANALYSIS OF SOILS.

The Method adopted by the Chemical Committee of the Agricultural Education Association.

THE object sought in mechanical analysis is to obtain an approximate estimate of the proportion in which particles of different sizes are present. It is pretty certain that in the case of the inorganic materials the size of the particles has a predominant influence on the physical and mechanical properties of the soil.

That is to say it may be fairly assumed that the effect of the various mineral substances present (with the exception, perhaps, of calcium carbonate) on the physical properties of the soil is far more dependent on the size of the particles than on their chemical nature.

At the same time it must be remembered that the mechanical texture and other physical properties of the soil will be profoundly affected also by the amount of organic matter present, and in regard to this constituent of the soil questions of the size of the particles are of less importance.

The minuter particles of the soil appear to be held together more or less closely by quasi-chemical as well as by more strictly physical forces, and as this coagulation is in part due to humus, it is needful to remove the humus, before or during the process of mechanical analysis. The humus in combination with bases in the soil should be liberated by preliminary extraction with dilute acid. This at the same time removes the calcium carbonate, which on the whole must be regarded as an advantage.

By this treatment with weak acid and subsequent extraction with ammonia all coagulation due to humus or calcium carbonate is destroyed, and the inorganic particles of the soil are set free from the temporary aggregations which may have been brought about by cultivation, yet the attack is not drastic enough to materially affect the sizes of the particles considered as individuals. The object is to ascertain the ultimate

inorganic structure of the soil, for example to show the essential identity in mineral structure of the soil of a pasture and an adjacent arable field on the same formation; leaving the analyst to judge from the variation in the proportion of humus, &c., what will be the difference at the time of sampling in the physical properties of the two soils. The treatment also serves to remove the potent flocculating and deflocculating effects of small quantities of salts in the soil.

It is evident, however, that a method based on the foregoing preliminaries cannot apply to soils of which a large proportion consists of the very materials (humus or calcium carbonate) that have been removed. In other words, the method is of only limited application to soils mainly composed of organic or calcareous matter.

While it is convenient to attach names to the various fractions into which the soil is divided by a mechanical analysis, instead of being continually forced to specify the limits of size, yet a very restricted choice of terms is available, nor have these always been used in the same sense by different experimenters. The terms used in the scheme below are in common use in connexion with the particles of earthy materials, are well understood, and convey the idea of gradation in size.

The term "Soluble Humus" is used to denote the organic material soluble in dilute ammonia after the soil has been washed with acid.

General Principles of the Method.

The soil (*i.e.*, air-dried fine earth, which has passed a 3 mm. sieve) is allowed to remain in contact with dilute hydrochloric acid, N/5 HCl containing 1 gram-molecule in 5 litres, until effervescence ceases. It is then washed on a filter until all acid is removed.

The solid residue is now well rubbed up by means of a rubber pestle (made by sticking a glass rod as handle into an inverted rubber stopper) with dilute aqueous ammonia and, after removal of the coarser particles by sieves, separated into fractions by the beaker method of sedimentation. Lipped beakers of approximately the same size and shape are provided with a strip of paper at the back, marking a particular height. In these the material is well rubbed up with the rubber pestle, the water brought up to the mark, thoroughly agitated and the pestle removed. The beaker is now allowed to stand for a given time and the turbid liquid is poured off into another beaker. The particles which had fallen to the bottom of the beaker are again worked up with the rubber pestle in the dilute ammonia, and the operation of settling for

the same time from the same height is repeated. When the operation has been repeated 8—10 times it will be found that the whole of the particles A within the beaker settle down within the given time, whereas the particles B which have been poured off are too small to fall through the given height in the time chosen. By taking a shorter time or a greater height particles A can be further subdivided, as also particles B, by choosing a longer time or a lesser height.

The individual analyst can arrange times or heights to secure a group of particles lying within any desired limits of size using the microscope to check the grade of sediment which is being attained. The order in which the different elutriations are carried out is also a matter of convenience.

In order to secure uniformity, and that the results of different analysts may be comparable, it is recommended that the following limits of size for the various groups of particles be adopted, and that any worker using a smaller number of groups will still make his division at the suggested limits, so that one of his groups may include exactly two or three of the specified groups.

The limits given below can only be looked upon as approximately exact. Whatever limits are fixed a little overlapping of the different divisions will always be found.

	Diameters in millimetres		Proposed Name	
	Maximum	Minimum		
Stones and Gravel ...	—	25	Stones	Separated by Sifting
	25	10	Small stones	
	10	3	Gravel	
Earth..................	3	1	Fine gravel	
	1	·2	Coarse sand	
	·200	·040	Fine sand	Separated by Subsidence
	·040	·010	Silt	
	·010	·002	Fine silt	
	·002	—	Clay	

The above substances should all be weighed after drying in the steam-oven; it is useful to give, also, the weight after ignition.

On the next page details are given of a method of procedure for carrying out this process.

It is desirable that as many measurements as possible should be accumulated of the sizes obtained by sedimentation for particular periods and various depths of falling, as the correspondence between the periods specified and the above sizes is only approximate as yet.

METHOD OF ANALYSIS.

1. 10 grams of the air-dry earth which has passed a 3 mm. sieve are weighed out into a porcelain basin and worked up with 100 c.c. of N/5 hydrochloric acid, the acid being renewed if much carbonate of lime is present. After standing in contact with the acid for one hour the whole is thrown upon a dried, tared filter, and washed until free of acid. The filter and its contents are dried and weighed. The loss represents hygroscopic moisture and material dissolved by the acid.

2. The soil is now washed off the filter with dilute ammoniacal water on to a small sieve of 100 meshes to the linear inch, the portion passing through being collected in a beaker marked at 10, 8·5 and 7·5 cm. respectively from the bottom. The portion which remains upon the sieve is dried and weighed. It is then divided into "Fine Gravel" and "Coarse Sand," by means of a sieve with round holes of 1 mm. diameter. The portion which does not pass this sieve is the "Fine Gravel." This should be dried and weighed. The difference gives the "Coarse Sand." If required both these fractions can also be weighed after ignition.

3. The portion which passed the sieve of 100 meshes per linear inch is well worked up with a rubber pestle, and the beaker filled to the 8·5 cm. mark and allowed to stand 24 hours. The ammoniacal liquid which contains the "Clay" is then decanted off into a Winchester quart. This operation is repeated as long as any matter remains in suspension for 24 hours. The liquid containing the "Clay" is either evaporated in bulk, or measured and, after being well shaken, an aliquot portion taken and evaporated. In either case the dried residue consists of "Clay" and "Soluble Humus." After ignition the residue gives the "Clay," and the loss on ignition the "Soluble Humus."

4. The sediment from which the "Clay" has been removed is worked up as before in the beaker, which is filled to the 10 cm. mark and allowed to stand for 100 seconds. The operation is repeated till the "Fine Sand" settled in 100 secs. is clean, when it is collected, dried and weighed.

5. The turbid liquid poured off from the "Fine Sand" is collected in a Winchester quart, or other suitable vessel, allowed to settle and the clear liquid syphoned or decanted off. The sediment is then washed into the marked beaker and made up to the 7·5 cm. mark. After stirring, it is allowed to settle for 12½ minutes, and the liquid decanted off. The operation is then repeated as before till all the sediment sinks

in $12\frac{1}{2}$ minutes, leaving the liquid quite clear. The sediment obtained is the "Silt" which is dried and weighed as usual. The liquid contains the "Fine Silt" which, when it has settled down, can be separated by decanting off the clear liquid, and dried and weighed.

6. Determinations are made of the "Moisture" and "Loss on Ignition" of another 10 grams of the air-dry earth. The sum of the weights of the fractions after ignition plus loss on ignition plus moisture plus material dissolved in weak acid should approximate to 10 grams.

7. It is advisable to make a determination of the "Fine Gravel" in a portion of 50 grams of the air-dry earth. The soil should be treated with acid, as in 1, and after that is removed by decantation may be at once treated with dilute ammonia and washed on the sieve with 1 mm. round holes. The "Fine Gravel" left on the sieve is then dried and weighed, and the percentage found should agree with that found in 2. If it does not the result now found should be taken as the true one.

CORRESPONDENCE.

MENDEL'S LAWS OF INHERITANCE AND WHEAT BREEDING.

IN a paper dealing with the application of Mendel's Laws to wheat-breeding, I described a series of experiments which led me to conclude that immunity and susceptibility to the attacks of yellow rust form a pair of "characters" in the Mendelian sense of the word[1]. The data were obtained from a single experiment, yet I felt that the only course open to me was to publish them at once, leaving the discussion of the problems this conception opens up until further evidence was available. One of the objects I had in view in planning this particular part of the work was to determine whether there was any real hope of obtaining satisfactory rust-resistant wheats. From the breeder's point of view it appeared to me that if the mycoplasm hypothesis is true, *i.e.* if the young plant actually inherits the rust itself from its parent, this is not a promising line of research. Setting aside, therefore, for the time being any other views as to what constitutes immunity, I examined my results in the light of the mycoplasm hypothesis. As I pointed out, this failed to account for the fact that an immune wheat when crossed by a susceptible one gave rise to a susceptible progeny, though it was sufficient to explain the susceptibility of the hybrid obtained as the result of the reciprocal cross. I further speculated on the possibility of the generative nuclei bearing the hypothetical mycoplasm.

Butler, in a recent paper[2], criticises my conclusions, and considers that they have no bearing on the mycoplasm hypothesis.

The following excerpts from Eriksson's latest publication on the subject of the mycoplasm hypothesis will, I think, save me from the necessity of discussing Butler's arguments in detail, and show that my criticism was not altogether irrelevant: "Wie die Sache jetzt liegt, scheint es mir gar nicht unmöglich oder unsinnig zu sein an eine

[1] Biffen. *Journ. Agric. Science*, Vol. I. p. 40.
[2] Butler. *Journ. Agric. Science*, Vol. I. p. 361.

Erblichkeit der Krankheitsanlage auch dass männliche Organ, die Pollenkörner, zu denken," and further, "... so hat man wenigstens mit der Möglichkeit zu rechen, dass auch die Gewebe der Staubblätter, und zwar speziell die der Antheren, mycoplasma führend sein können[1]."

It is difficult to treat in detail one of the broad questions raised by Butler for lack of evidence one way or the other. It may at once be stated, however, that it is a well-recognized fact that immunity to yellow rust does not necessarily imply immunity to any other rust. Michigan Bronze, for instance, is intensely susceptible to yellow rust, but practically immune to black and brown rust. An inspection of the tables in Eriksson's *Die Getreiderost*[2] will provide numerous other examples.

But the question as to how far characters alter with a change of locality is still an open one, which can only be answered by the cooperation of a number of workers in different districts. Its importance is so obvious that it may serve a useful purpose if I point out some of the typical difficulties already encountered in this part of the research. Butler's paper provides two examples out of the three he quotes as illustrating this possibility. The first is "the striking case of spelt wheat which has proved very resistant in some parts of India and not in others." Spelt wheat is a generic term, for there are a large number of varieties of spelts in cultivation. Thus in my own experiments I have had occasion to grow nearly thirty, some of which were obtained from India. Amongst those are some varieties which are the most immune to yellow rust I possess, whilst others are second only to Michigan Bronze in susceptibility. If, as I suspect, the evidence for this particular case rests on a generalization from the various spelt crops as seen here and there in the country it is of no particular value. To be satisfactory it would have to be based on a critical experiment with one variety distributed over various districts and kept under observation for a number of seasons. Of such an experiment I can, however, find no mention.

The second example is provided by the rust resistant hybrids raised by Farrar in New South Wales, which have proved susceptible in India.

The question which at once arises is "Were they ever rust-resistant?" Had such varieties ever been tested for a sufficient number of years in Australia before being tried in India?

One has to be critical on such a point, for a variety of wheat may escape rust for a season or two and then, owing to conditions of which

[1] Eriksson. *Arkiv för Botanik.*, 1905, Bd. 5, p. 54.

[2] For wheats, p. 333 *et seq.*; for barleys, p. 344 *et seq.*

we are ignorant, become badly attacked. That this has been the case with Farrar's hybrids is clear. Thus in a communication referring to the hybrid "Bobs," Farrar writes[1], "I mentioned that it was rust-free in 1903 at the Hawkesbury College Farm, and it was on that account that I suggested that we might have in it a variety which would prove to be safe to grow in the coastal counties. In 1904, however, 'Bobs' failed to resist this pest at Richmond as well as other places in the county of Cumberland, but was in fact smitten hip and thigh by the pest....... Still the matter is disappointing; but it is nothing more, and this failure cannot be regarded as a final failure to get varieties which will withstand rust in the coastal counties."

Of the third case, that of *Kathia* wheat, I can find no further data as to its behaviour outside of the United States, but I think that enough has been said to make one cautious of the statement so frequently made that characters will alter with a change of locality. That physiological characters do so is clear in certain cases, but we badly need really definite evidence on this point with regard to rust-resistance.

R. H. BIFFEN.

THE SUPPLY OF NITRATE TO THE SURFACE SOIL FROM THE UNDERGROUND WATER.

IN Mr A. D. Hall's interesting paper on the "Fertility of Land allowed to run wild[2]," he attributes a part of the accumulated nitrogen to "capillary creep" of nitrates from the underground water. In the present very imperfect state of our knowledge as to the actual velocity at which water moves vertically through the soil during dry weather, together with a corresponding absence of exact information regarding the diffusion of salts in the soil, it would be impossible to prove the truth of Mr Hall's assumption. But there are several arguments of a circumstantial nature, which may be advanced to disprove it.

In the first place these underground waters will contain chlorides as well as nitrates, and if the one be brought to the surface in the manner suggested so must the other. I do not know of any analyses of Rothamsted well waters, but usually such water contains at least

[1] Farrar. *Agric. Gaz. of N.S.W.*, 1905, p. 262.
[2] *Journ. Agric. Science*, Vol. I. p. 241.

several times as much chloride as nitrate, and indeed the disparity is commonly very great.

Mr Hall naturally does not suggest that any particular portion of the accumulated nitrogen in the soils is due to the underground water, but from the fact that this source is mentioned at all it is to be assumed that a *material* part of the whole is meant. Assuming such to be one-tenth, it would mean that of the ·037 per cent. increase of nitrogen in the surface soil of the Broadbalk field, ·0037 is referable to the supply in question, or of the ·023 per cent. accumulation in the Geescroft surface soil, ·0023 per cent. is from the same source. There is no need to consider the gains of nitrogen in the lower depths of the soil for the purpose in view.

If this underground water contains equivalent quantities of chloride, then there should be a similar accumulation of chlorine; or if, as is much more probable, the ratio of chlorine to nitrate-nitrogen in the underground water is 10 : 1 or even a wider ratio, then the accumulation of chlorine should be, say, $\cdot0037 \times 10 = \cdot037$ or $\cdot0023 \times 10 = \cdot023$ respectively. On this point Mr Hall's paper gives no information.

The quantity of chlorine in the Broadbalk and Hoos fields soil is, however, stated in the Lawes Agricultural Trust lectures by Dyer[1], and there is, as a matter of fact, in the Broadbalk field somewhat more chloride in the second depth of 9 inches than in the lower strata. The difference varies from one part to eight parts per million of soil, and for most plots it is only two or three. Eight parts per million is equal to ·0008 per hundred of soil, and if only the unmanured plots are considered the quantity falls to ·0001 per cent. chlorine. In the Hoos field there is no such increased quantity of chlorine in the second depth.

This is far smaller than the quantity of chloride which should be found if any material portion of the accumulated nitrogen in the uncultivated patch of Broadbalk field had been derived from underground water.

As a matter of fact there is no reason for supposing that the larger quantity of chloride in the second 9 inches of soil in the Broadbalk field was derived at all from underground water. The higher concentration in this depth is much more readily explained by the effects of season.

Then, too, if salts pass from the underground water to the surface and accumulate there, it means that on the whole a greater quantity of

[1] United States Department of Agriculture, Office of Experiment Stations, *Bulletin* No. 106, 1902.

salt moves annually in this direction than downwards. If this is so it follows that a greater quantity of water does likewise, and that there is a net loss of underground water, or in other words that the underground water is not derived from percolation at all but from some other source. It is, however, well established that in many or most situations the underground water is due solely to percolation.

There are also other arguments which may be advanced against the assumption that salts ever reach the surface from underground water, unless the latter is within 3 or 4 ft. of the surface.

One is that in any country with a rainfall distributed well over the year as in England, percolation is in progress more or less all the year through; such movement of water is much more rapid than the opposite one; and the resultant effect must be a general downward movement of the salts rather than the converse. Even in India, with five or six months of dry weather and a much higher temperature than that of Europe, it is not usual to find any accumulation of salts in the surface soil where the underground water contains high proportions of nitrates and chlorides. For, example, the very saline well waters of Gujarat[1], and Muttra[2] are situated below very fertile and non-saline soils. *Usar* land is not here forgotten, but this special case does not negative the more common one. If the underground water happens to lie less than about 5 ft. from the surface, such an accumulation may occur, but these conditions are exceptional.

Again, the fact that the amount of evaporation is the same from the 20″ and 60″ gauges at Rothamsted is a proof that the underground water supply does not affect the amount of water evaporated, for if it did the 60″ gauge should lose more than the 20″ gauge.

If the absence of accumulated chlorine were accounted for on the assumption that both this element and the nitrate do come with the underground water during dry weather, when the nitrate is arrested by vegetation, but that later with the next rain the chlorine is washed down again, such an argument implies that this can happen during such short dry periods as are experienced at Rothamsted; that also the whole of the water in the soil down to the underground water also passes in the same short period to the surface (and evaporates), and that during the next wet period enough rain falls to wash down again the accumulation of chloride and other salts to their original position at the underground water level. Such an assumption implies a movement

[1] *Vide Agricultural Ledger*; No. 14 of 1895.

[2] *Vide Transactions of the Chemical Society*, Vol. LXXXI.

of water far greater than actually occurs. Admittedly this velocity is not known with any great precision, but even the most extravagant of the various laboratory experiments which have been made to exhibit the rate of rise of water through soils, have not shown such a velocity as the foregoing case would require.

J. WALTER LEATHER.

I agree with Dr Leather that capillarity would bring up chlorides as well as nitrates, but on the first rainfall sufficient to cause percolation down would go the chlorides again, the nitrates having meantime been taken up by the crop. Mr Warington has shown[1] that such returns of nitrate from the subsoil to the surface can take place. It is, however, arguable that capillary uplift will only bring back to the surface nitrates which had been made there and then washed down, but this ignores all possibility of diffusion or of lateral displacements of the whole body of soil water. How otherwise does a tree in a paved street get its nitrogen except by the lateral influx of nitrates in the soil water?

A. D. HALL.

[1] *Trans. Highland and Agric. Soc.* 1905.

REVIEW.

The Book of the Rothamsted Experiments. A. D. HALL, M.A. [John Murray, Albemarle Street, London, W.] Those who were privileged to associate personally with Lawes and Gilbert on the scene of their labours will recollect that a walk over the farm or through the Park with either of them—perhaps more especially with Lawes—seldom failed to be conversationally suggestive of how much potential knowledge remained still unextracted from the materials they had accumulated. Of the materials themselves much yet remains to be given to the world; but even of the immense mass of work that has been actually recorded and developed by full discussion in the long array of memoirs proceeding, directly and indirectly, from Rothamsted, much has appealed very little to those outside of the circle of advanced and diligent students, owing, perhaps, to the fact that the recorders devoted themselves rather to the accumulation and record of knowledge than to its popular diffusion. Indeed, it has long been a matter of regret that, leaving aside the earlier broad generalisations that have become commonplace knowledge, so great a part of the fruit of sixty years' work has remained more or less hidden from a large section of the contemporary generations of those on whose behalf it was carried out.

The work, of course, has not been without its popular exponents, some of whom have taught through books, some through journals and newspapers, some from behind the lecture-table, and some by all three methods; and, of very necessity, all current treatises on agricultural chemistry are based, as regards not a small portion of their contents, on the Rothamsted results. Dr Fream's little book, now, however, 17 years old, formed a popular guide to the wheat, barley, and grass experiments; much has been done by Mr Warington—whose own classical work on nitrification, as readers will scarcely need to be reminded, was carried out in the Rothamsted laboratory; and many

others have also lent their aid in presenting the Rothamsted results to those who lacked time or energy to consult the original papers. The subject of nitrification, for instance, was ably and popularly treated by Mr Warington in the first series of American Lectures; but these are now out of print. Gilbert, in the second series of American Lectures, republished at home, gave a general review of much of the work, though scarcely in a form likely to appeal readily to readers of scant leisure. But until now we have lacked a really concise and—if the word may be pardoned—lively monograph presenting a general view of the whole field such as would enable an agricultural student who has been able to devote but a limited time to chemistry to make an all-round acquaintance with what has been done at Rothamsted, and such as would at the same time give to the practical farmer some grasp of the immediate import of the Rothamsted work in relation to the operations which he has to plan and direct in his everyday life.

It may be fairly said, however, that such a book is now before the public.

When Mr Hall succeeded to the directorship of the Rothamsted station, he realized that he had a duplex task before him. There was the work of investigation, to be continued on the lines marked out by his illustrious predecessors, and extended in new directions indicated by the progress of modern knowledge and the requirements of the times. But there was also the work of popular diffusion, not only of what should be, but of what already had been, done. This task he has taken up with the ardour and ability which were expected from him by those who knew his enthusiasm and experience as a teacher; and this book forms an important contribution to its fulfilment.

The excellent biographical sketches of Lawes and Gilbert, written by Mr Warington, which appeared in the obituary notices of the Royal Society, are reproduced as a fitting introduction, and the book is divided into thirteen chapters, dealing respectively with the investigations relating to the sources of the nitrogen of vegetation; with the meteorological observations; with the composition of the Rothamsted soil; with the experiments on wheat, on barley, on oats, on root crops, on leguminous crops, on grass, and on crops grown in rotation; with the feeding experiments, and with such miscellaneous enquiries as those relating to sewage irrigation, to the relative nutritive value of malt and barley, to ensilage, and to the composition of the wheat grain and its milling products.

In summarising and illustrating many of the results, Mr Hall has

followed what, in relation to Rothamsted, must be regarded as the new departure already made in some of his published papers, in adopting the use of graphic and diagrammatic presentation—a mode of illustration which should appeal more readily to the eye and to the understanding than the juxtaposition of mere numerals. This form of presentation has of late years gained rapidly in popularity, and has been freely used by agricultural writers on the Continent and in America. But it was not in vogue in the earlier days of Lawes and Gilbert, and the latter could never bring himself to approve of or to appreciate the utility of graphic methods—graphic methods, that is to say, which were symbolic, as apart from comparative photographs and pictures. The conservatism of Gilbert in this respect undoubtedly detracted from the readiness of intelligibility of many of the Rothamsted memoirs to those whose time for reading was limited. To Gilbert's eye and mind a page of tabulated figures was very easily intelligible, whereas the same results thrown into curves or rectilinear projection appealed little to him until he had translated them into numerals—thus reversing the mental habit of the student trained in the more modern school. It is true that Professor Armstrong, for the purpose of the delivery of his third series of American Lectures, constructed a valuable series of curve diagrams illustrative of the results of the continuous field experiments; but these have not yet been presented in published form. This, therefore, is the first time that anything like free diagrammatic representation of the Rothamsted work has been provided for the general reader. In the present book, which, after all, is but a summary, graphic illustration is, of course, necessarily confined to some of the more striking and salient facts, but it must be regarded as a valuable feature.

To the busy student and to the ordinary agricultural reader, the greatest service rendered by the author is perhaps that furnished in the "Practical Conclusions" appended to each chapter, relating to the department of work to which it is devoted. Some of these conclusions are, it is true, to be found embodied in the original memoirs, but by no means all of them. Mr Hall has evidently devoted very diligent labour to the digestion and assimilation of the material at his disposal, and has given in succinct form the valuable product of the metabolic mental process to which he has subjected it. By way of further appendix to each chapter he also gives, for the sake of those who wish for fuller details, a complete table of reference to the various original memoirs bearing upon the work dealt with in the chapter; and at

the end of the book there is a complete list, not only of the 184 publications which have directly emanated from Rothamsted, but also of 19 papers by other investigators dealing with Rothamsted material, and of 16 other publications dealing with the experiments from one point of view or another.

Lastly it may be added that the book is well got up and printed in large, legible type, on good paper. It is a book which no agricultural teacher will be able to afford to dispense with, and every serious student of agriculture will do well to provide himself with a copy of it.

BERNARD DYER.